Mechanical Drawing *for* High Schools

BOOK I

Elementary and Intermediate Courses

Geometric Constructions—Working Drawings—Simple Projections—Advanced Projections—Practical Problems—Isometric and Cabinet Projections

BY

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Atkinson, Mentzer & Company, *Publishers*

BOSTON   NEW YORK   CHICAGO   DALLAS

PREFACE

The authors long have maintained that, logically, a printed text in the hands of the pupils is as essential to the proper presentation of the subject of Mechanical Drawing as like texts are necessary to the right teaching of other branches of mathematics in the high schools.

The results of their own experiments in this direction have convinced them of the great helpfulness of such a text to the pupil and to the teacher alike, and of the superiority of this over the oral method of instruction, so long and so generally followed.

Furthermore, it is their belief that, as in other subjects, even approximate uniformity in the teaching of this subject can be secured only by the general use of a uniform text as the basis of instruction.

Technical institutions for years have used such courses, but these are too advanced and too highly technical for secondary school use.

Hence, since no complete courses written especially for the academic high schools are available, the authors, a committee created for the purpose, have endeavored to prepare one, hoping that, by its introduction, the work in this subject may be generally improved and that something like uniformity in it may be secured.

In brief, the course consists of several groups of problems, one or more groups for each school year.

The theoretic and the practical problems of each group have been carefully selected, arranged progressively, and presented simply and clearly in language largely conversational in style, the intention being to talk the subject to the pupil on paper, as it were. In fact, in so far as space would permit, the text was written for self-instruction. For obvious reasons, however, the teacher is not eliminated altogether.

Each group of problems is introduced by an illustrated text explanatory of the practical purposes of such problems, and of the general methods and principles involved in their solution. Furthermore, where necessary, in the lower years more especially, each problem is accompanied by explicit directions for laying out, and by specific suggestions for its solution.

Principles and their practical application have been emphasized all through, for these, and not the mere solving of a stated number of problems, constitute the essentials to be taught. With this purpose in mind, the teacher can readily shape his instruction, based on the course, so as to add variety to the work, and to meet the differing abilities of his pupils. The problems, as herein given, he need not adhere to rigidly in detail, but to the methods and to the principles set forth, he should.

Numerous instances prove that, aside from the educational worth of the training he secures through this subject as a branch of mathematics and as an art, guided by instructions systematically given and complying with the exactions of a thorough course, the pupil will acquire a skill in and a working knowledge of practical drafting which will be of definite commercial value to him, should he desire to turn them to account.

Upon the text of the first three years the authors collaborated, while each assumed individually the preparation of that one of the fourth year courses which bears his name.

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Chicago, Ill.,
September 30th, 1909.

LIST OF NECESSARY DRAWING MATERIALS.

Set of drawing instruments in a case, comprising:
  One pair of 5″ compasses with attachments, namely: A pencil leg, a compass pen, and an extension bar. One pair of 4½″ dividers (a combined compass and dividers will not do). One straight line pen. One 3½″ spring-bow pen (desirable, but not absolutely necessary).

Drawing board, 20″ by 24″.

Triangle, 9″—30 and 60 degrees.

Triangle, 7⅛″—45 degrees.

Tee square, 24″ blade.

Architect's, triangular, boxwood scale, 12″ long.

Paper for first year class, 19″x24″ (making two plates).

Lettering paper for exercises in lettering.

Bottle of Higgin's waterproof black India ink.

Bottle of Higgin's red India ink (optional with teacher).

4H lead pencil, and stick of 6H lead for compasses.

One-half dozen thumb tacks.

Pencil and ink eraser, chamois skin, and sandpaper.

Portfolio for plates, 15″x22″.

Additional Materials Needed for Second, Third, and Fourth Year Work.

Tinting outfit, comprising:
  A camel's hair water-color brush, double ended, large and medium size.
  Tinting slab or nest of three 2″ saucers.
  A stick of India ink or a pan of water-color for tint (sepia or gray).
  Two small, handleless, enameled cups for water.

Paper for this work: Whatman's cold pressed, 22″ by 30″, making two plates, each 15″ by 22″.

Bottle of Higgin's red India ink.

FIRST YEAR.

INTRODUCTORY TEXT.

The study of constructive drawing or mechanical drafting aids in developing the reasoning powers, as do other branches of applied mathematics, strengthens inventive and constructive ability, and tends to develop in the pupil the love for systematic, precise, and neat work which will always add to the desirability of his services in any capacity.

Furthermore, a knowledge of its principles is of value to men in almost every occupation. Accordingly, this course aims to familiarize the pupil with the underlying principles of those methods of mechanical representation in general use which are most necessary to the practical draftsman.

However, it is not alone a knowledge of "the why" and "the how" that makes a draftsman, but it is this knowledge of principles and methods coupled with the essentials of good workmanship—namely, ACCURACY, THOROUGHNESS and NEATNESS, all of which will be demanded of the student at the higher technical school and in the professional world. Let him be accurate, thorough, and neat **as a matter of principle** right from the start, and get the habit early.

Directions for the Use of the Implements.

Leads.—Pencil and compass leads should be 4H and 6H respectively, and should be sharpened wedge-shaped. Always carry the pencil lightly, as any pressure upon such hard leads will make a furrow in the paper which will be difficult to remove.

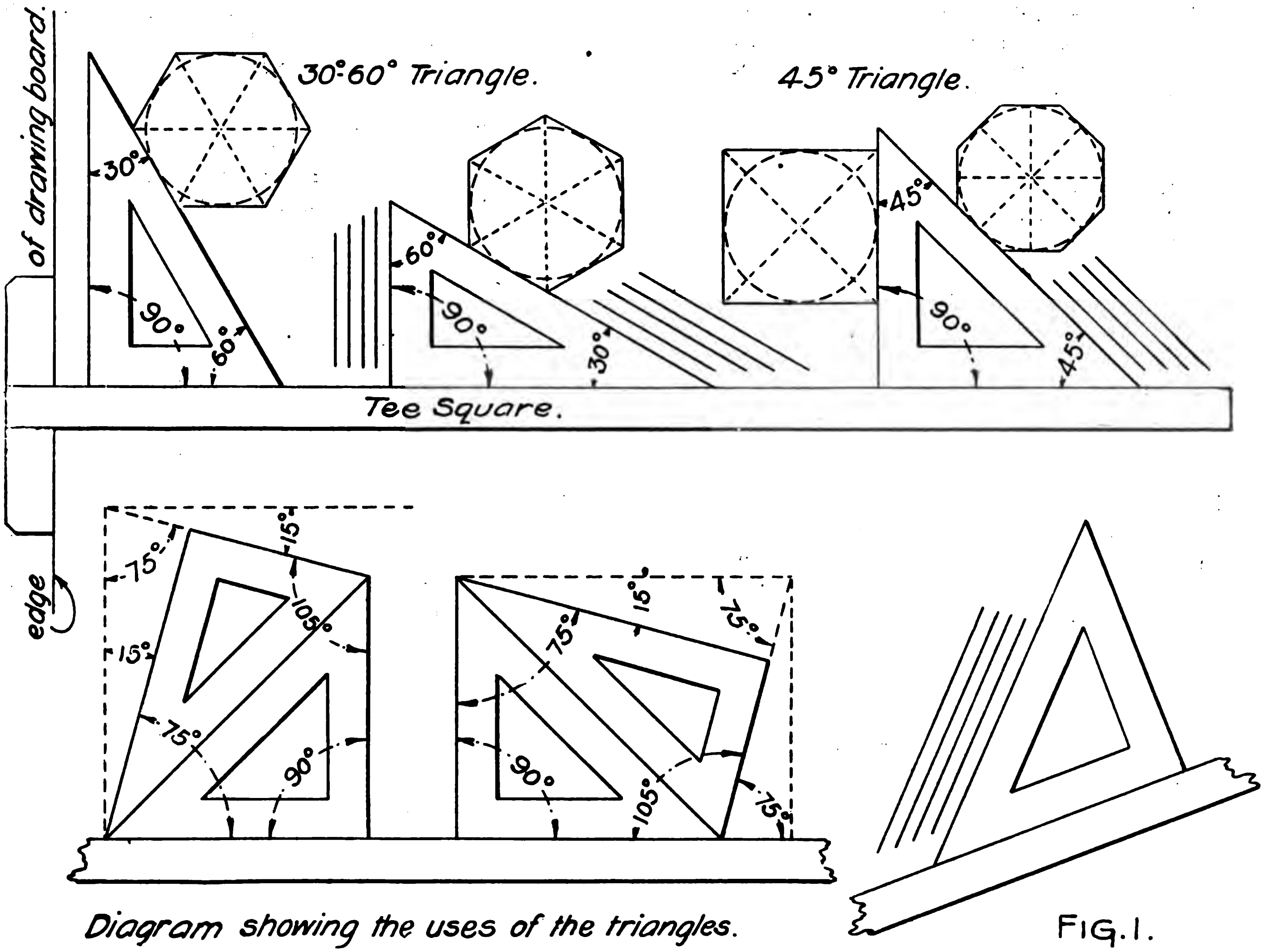


Diagram showing the uses of the triangles.

FIG. 1.

Tee Square and Triangles.—Use the tee square from the left edge of the drawing board always, and in drawing with the tee square and the triangles always use the farther edge, working from left to right or from you.

Use the tee square with the head tight against the left edge of the board for all horizontal lines, and the triangles held against the tee square in the position shown in Fig. 1 for all vertical lines and lines at angles of 15, 30, 45, 60 and 75 degrees to either the vertical or horizontal, as shown in the figure.

By using the tee square held obliquely, in combination with a triangle as a straight edge, parallel lines at any angle may be drawn, and also lines at 15, 30, 45, 60, and 75 degrees to these oblique lines.

By the use of the tee square and the triangles, circles may be subdivided into 2, 3, 4, 6, 8, 12, and 24 equal parts.

Compass and Dividers.—Let the compass and the dividers rest upon the paper with their own weight and manipulate them from the head with the thumb and the first two fingers; do not bear down on them or grasp the pencil leg or the pen with the other hand while tracing a line. Avoid putting pressure on the dividers in stepping off distances and in subdividing lines.

Accuracy.—By accuracy is meant not only exactness in laying off lines and angles, but also exactness in subdividing them, in connecting points, in making intersections, in drawing perpendiculars, parallels, and tangents, in locating centers of circles, in joining arcs of different radii, etc.

Thoroughness.—By thoroughness is meant the evident disposition of the pupil or of the draftsman to make his drawing show clearly and fully all necessary information.

Neatness.—Under this heading comes all that adds to or detracts from the general appearance of the drawing, such as blots, erasures, uneven lines, poorly shaped letters of varying slants, misspelled words, etc. Besides this, a symmetrical and agreeably proportioned arrangement of the problems upon the plate is necessary in order that, as a whole, the work may seem to balance, and the effect, from an artistic standpoint, be pleasing.

Geometric Constructions.

"Geometry is that branch of mathematics which treats of position, form, and magnitude." It deals with the relations of points, surfaces, and solids.

Plane geometry treats of constructions and figures which lie wholly in one plane.

The study and execution of constructions in plane geometry train the pupil to some necessary skill in the use of the drafting instruments, provide him with various constructions of practical value to the draftsman, and give him an introduction to the subject of geometry by familiarizing him with many geometric terms and conceptions. For convenient reference, the definitions of various commonly used terms are here grouped.

Definitions of Geometric Terms.

Lines.—A point is that which has position but no magnitude. It is represented by a dot.

A line is that which has one dimension—namely, length.

A straight or right line is one having the same direction throughout its length.

A curved line or curve changes its direction at each succeeding point.

A horizontal line is one that is level throughout its length.

A vertical line is one that is perfectly erect—i. e., is parallel with a "plumb line."

Parallel lines are those that lie in the same plane and that would never meet if produced. They are equidistant throughout their length.

A perpendicular line is a straight line so meeting another that the two adjacent angles formed are equal. Each of these angles is called a right angle.

A right angle is divided into 90 equal parts called degrees.

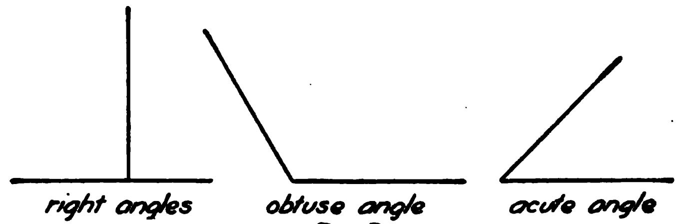


FIG. 2.

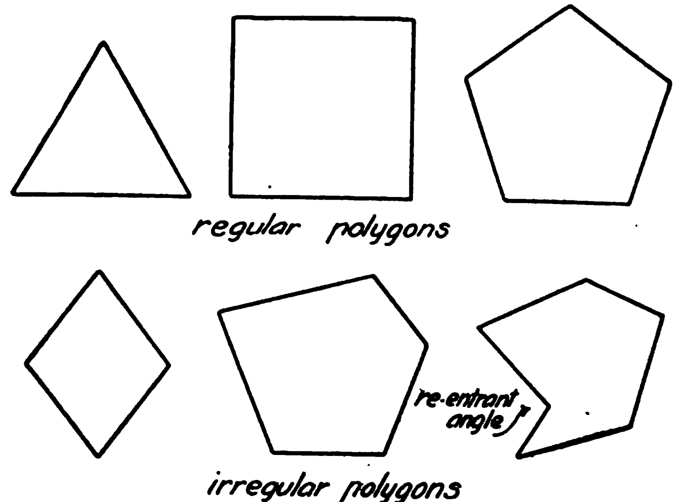


FIG. 3.

Angles.—When any two straight lines meet, or if produced, would meet in a point, the figure so formed is called an angle. The two lines are called the sides of the angle. The point of meeting of the sides of an angle is called the vertex.

The size of the angle is the amount of its opening and does not depend upon the length of its sides.

If the opening between its sides is greater than a right angle, the angle is an obtuse angle.

If the opening is less than a right angle, the angle is an acute angle.

Polygons.—A polygon is any angular plane figure bounded by straight lines.

If all its sides and all its angles are equal, it is a regular polygon.

If all its sides and all its angles are not equal, it is an irregular polygon.

Polygons are named according to their number of sides or the number and the kind of their angles; thus, a polygon of four sides is a quadrilateral; a polygon of three sides is a triangle, etc.

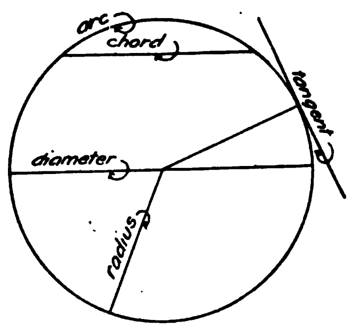


FIG. 4.

Circles.—A circle is a plane figure bounded by a curve, all points of which are equidistant from a point within called the center.

The boundary of a circle is called the circumference.

Any part of the circumference is called an arc.

Any straight line having its ends in the circumference is called a chord.

Any chord passing through the center is a diameter.

Any straight line from the center to the circumference is a radius.

Any straight line which touches a circle at but one point is a tangent. It is always perpendicular to a radius drawn to that point.

Planes.—A plane or plane surface is one in which the straight line connecting any two points will lie wholly within the surface. Example: The surface of a drawing board.

The definitions of the various solids will be taken up in connection with the subject of Working Drawings.

Lettering.—Ability to letter well and freely is as essential to the draftsman as ability to write well is to those following clerical pursuits.

Legibility is the first requisite of good lettering. This is secured through simplicity and correctness of shape of the letters, uniformity of slant and height, and proper spacing. Practice alone will bring facility.

In lettering the plates, print only the wording of the propositions and titles as given. It is often well to do this before the constructions are drawn. Always rule guide lines for the locations and the heights of the letters. Letter directly in ink, using an ordinary pen, without first penciling the letters, excepting for pretentious headings. Elsewhere than titles, use slant lettering, not vertical. Make the slant in lettering the same as in writing—i. e., about 70 degrees.

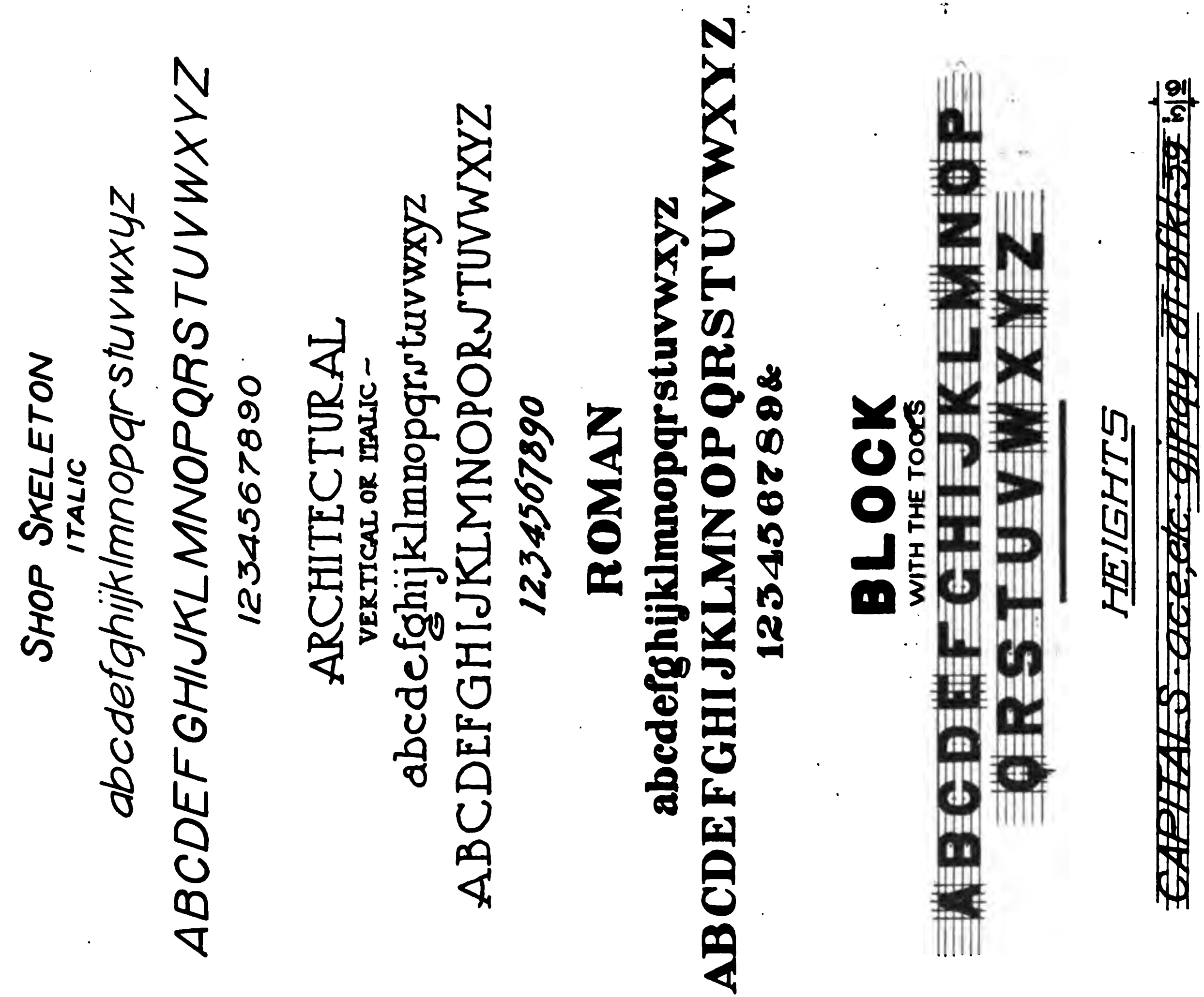

SHOP SKELETON
ITALIC
abcdefghijklmnopqrstuvwxyz
ABCDEFGHIJKLMNOPQRSTUVWXYZ
1234567890
ARCHITECTURAL
VERTICAL OR ITALIC
abcdefghijklmnopqrstuvwxyz
ABCDEFGHIJKLMNOPQRSTUVWXYZ
1234567890
ROMAN
abcdefghijklmnopqrstuvwxyz
ABCDEFGHIJKLMNOPQRSTUVWXYZ
1234567890&
BLOCK
WITH THE TOOLS
ABCDEFGHIJKLMNOP
QRSTUVWXYZ
HEIGHTS
CAPITALS ace, etc. gjpqy dt bfkl

Fig. 5.

Do not crowd the letters or the words. The space between two words should never be less than the width of the capital H of the alphabet used. Do no lettering outside of the border lines.

Examples of Alphabets and Numerals. Fig. 5.

These are standard alphabets and they give the correct shapes of the letters and numerals. **These shapes should be learned.** From these alphabets, other and more decorative ones may be easily derived, but on ordinary drawings, ornate printing is out of place. As previously stated, for general use, inclined letters are preferable because they are easier to make free-hand, hence more rapid of execution, and in them slight differences of slant are less noticeable than would be slight variations from the upright in vertical letters. Use Shop Skeleton for general detail work and, later, the Block, the Roman or the Architectural styles for titles, as is appropriate.

Widths.—Notice that **W** is the widest letter (about as 5+ : 4); that **M** is the next (about as 5— : 4), and that the **J** and the **I** are the narrowest (the former about as 3: 4), and that the others are uniformly of the width of the **H** as a standard.

Text of Problems.

Note.—Immediately following the problems here given for Plates 1, 2, 3, and 4 there are twelve others from which substitutions may be made or extra ones given, at the discretion of the teacher.

Plate 1. Fig. 6.

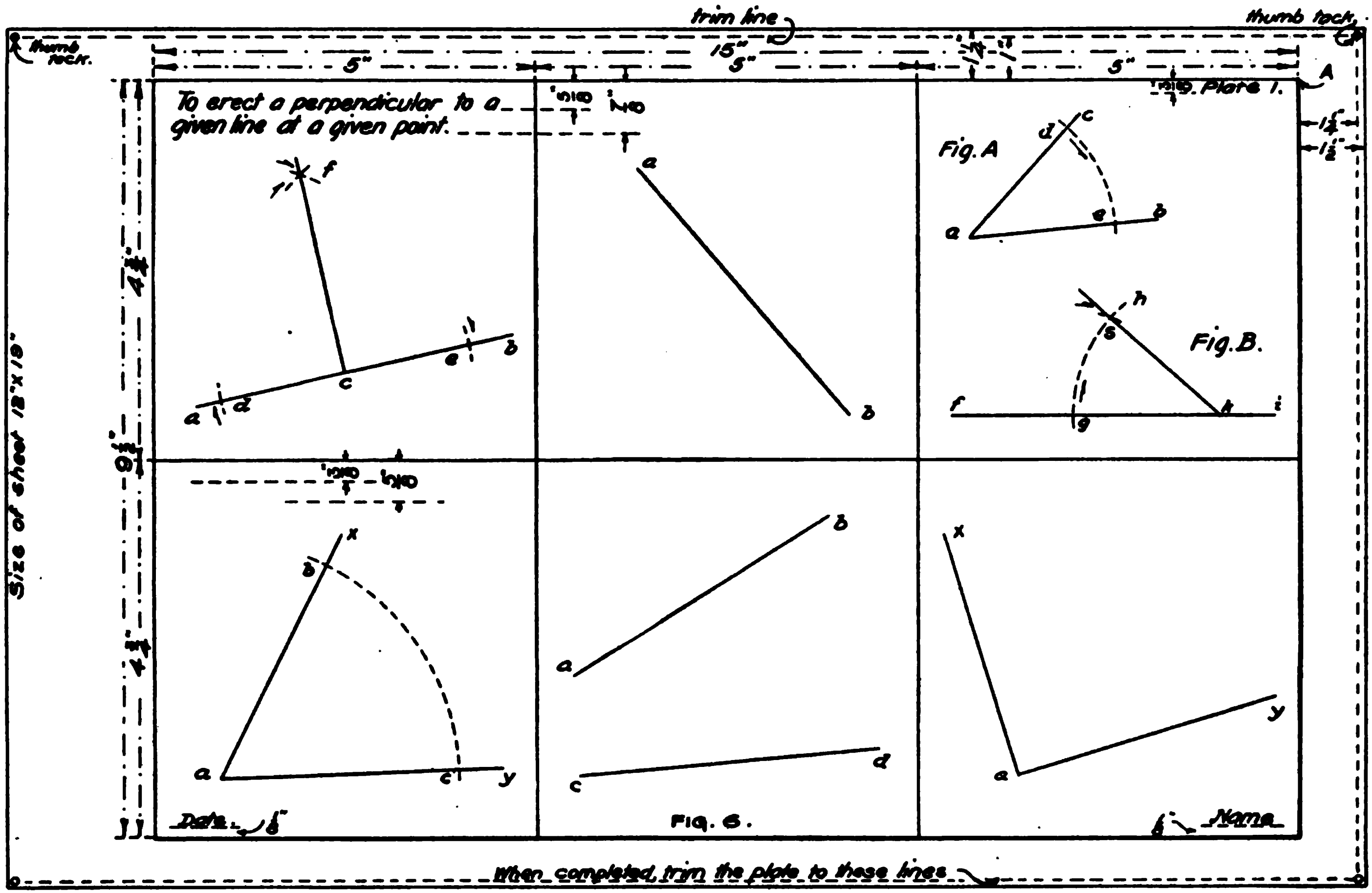
Lettering Exercise.—Before laying out this plate or the three following ones, the pupil is to print carefully, in class, as a freehand lettering exercise, first, a Shop Skeleton alphabet of small letters and numerals (Fig. 5), and then the "propositions" or statements of the problems about to be drawn. This is to be done on a card of the prepared lettering paper. Correctness of shape and uniformity of slant of the letters, also suitable spacing of the letters and of the words, are the things which the pupil must try to secure. When this card is done, the plate may be laid out according to the following directions:

General Directions.—The sheet of drawing paper is 12″ by 19″. Lay one of these on the drawing board with its longer edges about horizontal. Place the tee square over this, with its head tight against the left edge of the board; its blade will then be horizontal. Bring the upper edge of the sheet to the upper edge of the blade of the tee square. Then fasten the sheet firmly by placing thumb tacks in the corners as shown in Fig. 6.

With the tee square and a triangle draw a trim line ¼″ from the edge on three sides of the sheet (right, top, and bottom) to measure from and later to trim to.

From the upper right hand corner of this trim line, set off a point 1¼″ to the left and 1″ down, thus fixing a corner of the border line of the plate, point A, Fig. 6. From this corner point, draw a horizontal line 15″ long and a vertical line 9½″ in length. From the ends of these lines draw the other lines necessary to complete a rectangle 9½″ by 15″.

Divide the longer side of the rectangle into three 5″ divisions and the shorter side into two 4¾″ divisions. Then, with the tee square and a triangle, draw from these points horizontal and vertical lines


trim line
thumb tack
thumb tack.
15"
5"
5"
5"
A
Plate 1.
To erect a perpendicular to a given line at a given point.
Fig. A
Fig. B.
Size of sheet 12"x15"
Date
Fig. 6.
Name
When completed trim the plate to these lines

subdividing the large rectangle into six smaller rectangles each 4¾″ by 5″. Later, in each of these rectangles, we will construct one of the problems.

Next, the pupil should print, at the top of the spaces, the statements of the problems. For these he must rule (in pencil only) the necessary guide lines, as shown in Fig. 6. In this printing he should strive to improve upon the work of his lettering exercise.

In the particulars of size and of position of the problems the pupil must be careful at all times. Drawings that are disproportioned to their surroundings or that are so placed that the plate seems unbalanced, look badly. They should be redrawn. And where there are several problems on the plate, each should be drawn of a size agreeable to the others. These are among the requisites of good workmanship.

All succeeding plates in geometry will be laid out as just described, and all plates of the first year will be of the same size as this one, that is, 9½″ by 15″ inside of the margin.

In problems where no solution or but a part of one is shown, the pupil must follow carefully the directions given and thus work out the solutions for himself. In doing this, mark each point described, by the letter given to it in the text, otherwise the solutions will be impossible.

The pupil should refer to the definitions in the introductory text for the meanings of unfamiliar terms in the following problems which are not therein explained.

Problem 1.—To erect a perpendicular to a given line at a given point.

Let **a-b** be the given line and **c** the given point. With **c** as the center, using any radius convenient, on the given line, set off **d** and **e** equidistant from **c**. With **d** and then **e** as centers and with any radius somewhat greater than **d-c**, draw arcs intersecting in point **f**. Draw **c-f**. This is the perpendicular required. In practice, the draftsman would draw this perpendicular with the triangles.

Problem 2.—To bisect a given line.

Let **a-b** be the given line. With centers in the ends **a** and **b**, using a radius greater than one-half of **a-b**, draw arcs intersecting in points **c** and **d** on opposite sides of the given line. Connect **c** and **d**. Point **e**, in which the line **c-d** cuts the given line, will be the point of bisection—i. e., the center of the given line.

Problem 3.—To transfer an angle.

Let **c-a-b** be the given angle, Fig. A. Anywhere, draw a line, as **f-i**, Fig. B, and assume any point in it, **k**, as the vertex of the required angle. In Fig. A, with the vertex, **a**, as the center, using any radius, draw an arc cutting the sides of the given angle in points **d** and **e**. In Fig. B, with center **k** and the radius just used, draw an indefinite arc, **h-g**. Take **d-e**, Fig. A, as a radius, and with **g**, Fig. B, as the center, cut the arc just drawn, in point **s**. Now draw a line from **k** through **s**. Then **s-k-f**, Fig. B, will be the required angle, being equal to the given angle, Fig. A, by construction.

Problem 4.—To bisect a given angle.

Let **x-a-y** be the given angle. With the vertex, **a**, as the center and with any radius, draw an arc cutting the sides of the angle in points **b** and **c**. With these points in turn as the centers and any radius greater than one-half of arc **b-c**, draw arcs intersecting outside arc **b-c** in point **d**. Draw **a-d**. This line bisects the given angle. To continue this process—i. e., to bisect the angles already formed—use **b**, **c**, and the

intermediate point just found on the arc **b-c,** as the centers from which to draw the necessary intersecting arcs, and then construct the bisectors of these smaller angles in the same manner as that used to find the bisector of the given angle. These bisectors also bisect the chords and the arcs of the angles.

Problem 5.—To bisect an angle the sides of which do not meet.

Let **a-b** and **c-d** be the sides of the given angle. By the use of the triangles draw a line parallel with **a-b** at any convenient distance therefrom, and at an equal distance from **c-d** draw a line parallel therewith, intersecting the first parallel. Bisect the angle thus formed. Its bisector also will bisect the angle formed by **a-b** and **c-d.**

Note.—To draw lines parallel with a given line by the use of the triangles, or a triangle and the tee square, see the introductory text, Fig. 1. In this case, let **a-b** be the given line. Place any edge of either triangle (preferably the shorter one) so that it coincides exactly with the given line. Place the other triangle or the tee square against either remaining edge, preferably the longer. Then, holding the second triangle or the tee square securely with the left hand, with the right, slide the first triangle where wished, keeping the edges in contact. Any lines drawn along the edge which in the first position coincided with the given line **a-b,** will be parallel with that line.

Problem 6.—To trisect a right angle.

Let **x-a-y** be the given right angle. With any radius and with point **a** as the center, draw an arc cutting the sides of the angle in points **b** and **c.** Using point **b** as the center and with **b-a** as the radius, draw an arc cutting the arc **b-c** in point **e.** In like manner, with point **c** as the center and with radius **c-a,** trace an arc cutting arc **b-c** in point **f.** Draw **a-e** and **a-f.** By these two lines the given angle is trisected. A right angle is the only angle that can be trisected by construction.

Inking.—Now, ink the constructions. In doing this, take great care to draw clean cut lines of even width, as shown in Fig. 7a, not as in Fig. 7b. Make dashes uniform in length, as shown in Fig. 8a, not as in Fig. 8b. Arcs should intersect and a line be passed

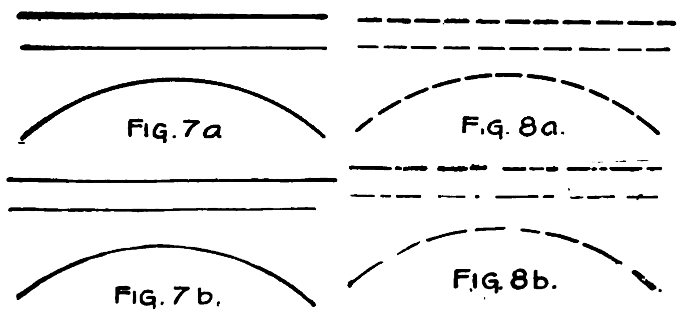


Fig. 7a

Fig. 8a.

Fig. 7b.

Fig. 8b.

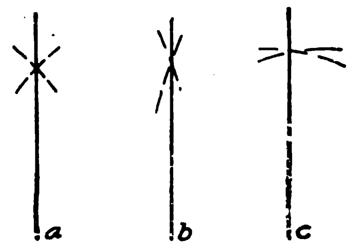


Fig. 9

through the point of intersection, as shown in Fig. 9a, not as in Fig. 9b, or as in Fig. 9c. Many adjacent

EXAMPLES OF LINES WITH THEIR USES.

1-For given and result lines in geometric constructions and subdivision lines of plates in geometry. For visible edges of objects represented in working drawings except "shadow-lines." BLACK.

2-For upper and left border lines of plates. Also for "shadow-lines." Rule for "shadow-lining" Make the lower and the right outlines of surfaces shadow-lines, excepting outlines common to two adjacent visible surfaces. BLACK.

3-For right and lower border lines of plates. BLACK.

4-For construction lines in geometry and for all lines representing invisible edges of objects. BLACK. For extension lines. RED.

5-For projection lines in working drawings. BLACK.

6-For axes or center lines and for dimension lines. RED.

NOTE:-Arrow heads and figures should always be BLACK, also the sign of feet (') and of inches (").

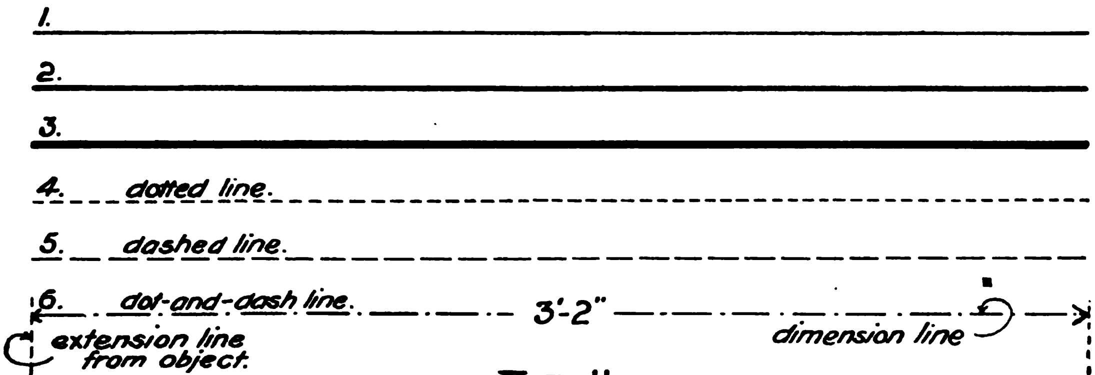


FIG. 11.

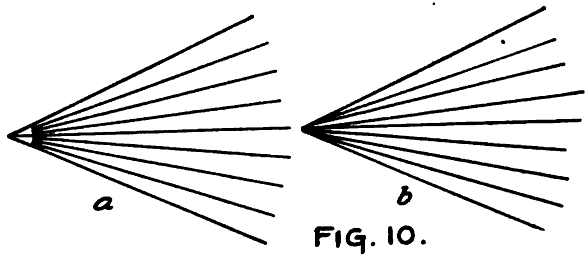


FIG. 10.

angles having a common vertex are best drawn as shown in Fig. 10a, not as in Fig. 10b.

Do not carry the point of the ruling pen close up to the straight edge, and be sure there is no ink on the outside of its blades. Carry the pen vertically, with the set screw away from the straight edge.

In geometrical constructions the lines used in the statement of the problem are the given lines. The lines used in combination with the given lines to determine points or lines are construction lines. The lines obtained as the solution of the problems are the result lines.

Of these, all construction lines should be inked dotted. All given and result lines should be inked solid. All lines used for the same purpose should be uniform in width. Given and result lines should be a trifle heavier than construction lines. See Fig. 11.

In general practice, ink all lines in this order:

1. Dotted arcs and circles.
2. Solid arcs and circles.
3. Dotted straight lines, including axes, etc.
4. Solid straight lines, including the subdivision and the border lines for the plates.

Do not ink the letters by which the various points in the problems were named. After inking, erase all pencil marks and trim the plate to the trim line.

Plate 2.

Do the lettering exercise as before directed. Then lay out the plate in accordance with the specifications given for Plate 1. However, in finishing, ink the subdivision lines as shown in Fig. 12. Print the headings for the problems, then commence their construction.

Problem 1-2.—To transfer a polygon (a) by parallels.

In the middle rectangle of the upper row, draw any irregular polygon of not less than seven sides, Fig. A. Do not copy the figure here shown.

To transfer this polygon, say to the first rectangle, and to construct it in exactly the same position as in Fig. A, transfer the angle formed by any one of its sides with either a horizontal or a vertical line, such as angle **1-b-c**, using the method shown in Prob. 3, Pl. 1. Then, taking them in order, add to the side thus transferred, **1-b**, the remaining sides of the polygon, drawing them parallel with the corresponding sides of the given polygon, by the use of the triangles as explained in the note to Prob. 5, Pl. 1. And, using the dividers, make each side of the polygon, Fig. B, in turn, equal in length to the like side of the polygon, Fig. A. Following this method, any angular figure may be transferred a short distance in any direction and still have the same position as the original.

Problem 2-3.—To transfer a polygon (b) by triangles.

To transfer or reconstruct the given polygon, Fig. A, anywhere, at random or in a required position, divide it into triangles, as shown. In the third rectangle, at any slant, draw the line **b′-1′** equal in length to the side of **b-1** of Fig. A. Taking point **b′** as the center, with **b-4** as a radius, drawn an indefinite arc. Then, with **1′** as a center, and **1-4** as a radius, draw an arc

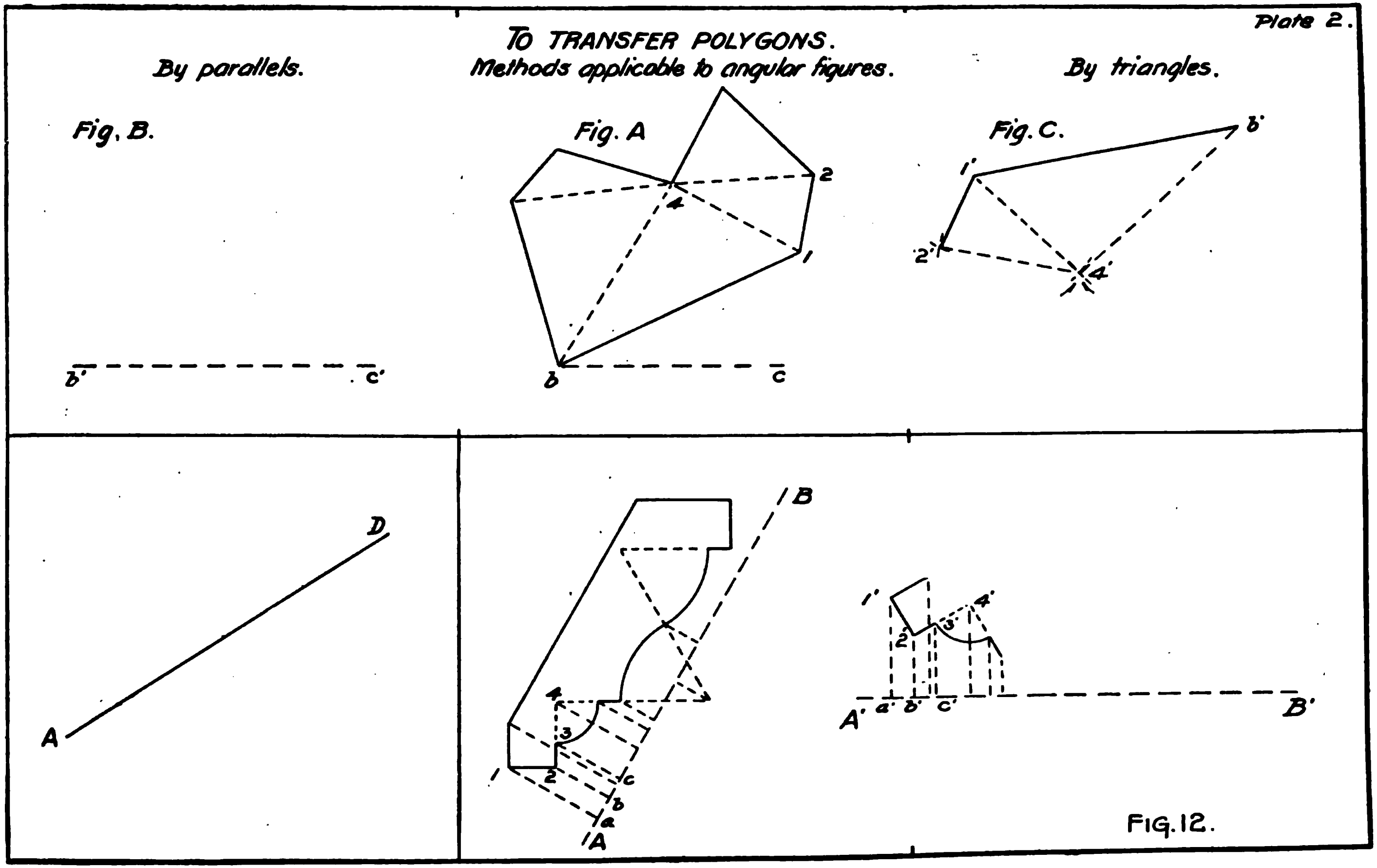


Plate 2.
TO TRANSFER POLYGONS.
Methods applicable to angular figures.
By parallels.
By triangles.
Fig. B.
Fig. A
Fig. C.
b' c'
b c
1 2 4
1' 2' 4' b'
A D
B
A
1 2 3 4
a b c
1' 2' 3' 4'
A' a' b' c' B'
FIG. 12.

cutting the first arc in **4′**. Draw lines **4′-1′** and **4′-b′**, thus constructing triangle **1′-4′-b′**. Now use side **1′-4′** as a base, and, with lines **1-2** and **4-2** of Fig. A as the radii for arcs intersecting in point **2′**, thus construct the triangle **1′-2′-4′**; thereby adding the side **1′-2′** to the figure. By continuing this process—i. e., by building up by triangles—the polygon may be reconstructed. Rule.—The known distances from two points to a third point will determine its location.

Problem 4.—To divide a given line into any required number of equal parts.

Let **A-D** be the given line. Draw, at any angle, an indefinite line from either end of the given line, as from **A**.. On this line set off from point **A** any unit as many times as there are wanted divisions of the given line **A-D**. Connect the last point (**c**) thus laid off, with **D**, the end of the given line. Parallel with the line **c-D**, from all other points on the indefinite line by the use of the triangles, draw lines cutting the given line. The divisions thus made will be equal and of the number required.

Problem 5-6.—To transfer a figure by co-ordinates, that is, by the use of equal measures.

Let the given figure have any outline made up of curves and straight lines. For convenience, but not necessarily, the curves may be circular, and the figure might resemble the cross section of a moulding, as shown, but do not copy this one.

Anywhere without the given figure, about parallel with its principal axis, draw a base line, **A-B**. To this base line draw a perpendicular from each angle of the figure and from the center of each arc. In the sixth rectangle, at a different inclination than that of **A-B**, draw a base line, **A′-B′**, for the new figure. Set off on this base line the distances **a′-b′**, **a′-c′**, etc., always taken from the initial point, **a′**, equal to the distances **a-b**, **a-c**, etc., on the original line, **A-B**. Erect a perpendicular at each of these points, **a′**, **b′**, **c′**, etc., making each equal respectively to the perpendicular from the like points in the given figure. Connect the points thus located (**1′**, **2′**, **3′**, **4′**, etc.) in the order in which they are numbered, thus duplicating the original figure.

In inking, always keep in mind the importance of nice lines.

Plate 3.

Lettering exercise; lay out of plate; statement of problems.

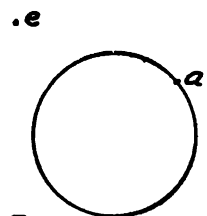


FIG. 13.

Problem 1.—To draw a right line tangent to a given circle and through a given point (A) on the circle, (B) without the circle. Fig. 13.

(A) With any radius, draw the given circle and assume any point in its circumference (**a**) as the given point. From the center, **c**, pass a line of indefinite length through point **a**. On this line set off a distance, (**a-d**), without the circle, equal to the radius, **a-c**. Construct a perpendicular to the line **c-d** at the point **a** (see Prob. 1, Pl. 1). This is the tangent required.

(B) Assume any point, as **e**, without the circumference. Connect this point with the center of the circle, **c**. Bisect this line **e-c** in the point **h** (see Prob. 2, Pl. 1). With **h** as the center and with **h-c** as the

radius, draw an arc cutting the circumference of the given circle in two points, **g** and **f**. These are the points of tangency for right lines passing through point **e**. Draw them exactly, as shown in Fig. 14a, not as in Fig. 14b, or as in Fig. 14c.

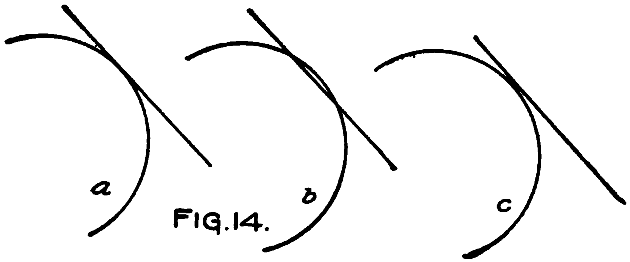


FIG.14.

Problem 2.—To inscribe a circle within and to circumscribe a circle about a given triangle.

Let **c-d-e** be the given triangle. Let it be irregular.

(A) Bisect any two angles of the triangle (Prob. 4, Pl. 1). The point of intersection of these bisectors (point **b**) will be the center of the inscribed circle—i. e., a circle that is tangent to all the sides of the triangle. It is also the center of the triangle. With this center and a radius to any side, draw the circle. The bisector of the third angle should pass through this point. Use this as a test of the accuracy of the first work.

(B) Construct the perpendicular bisectors of any two sides and extend them to their intersection in point **a**. This will be the center for the circumscribing circle—i. e., one which can be drawn through all of the angles of the triangle. The perpendicular bisector of the third side should also pass through this point **a**. Use this as a test of the accuracy of the first bisections.

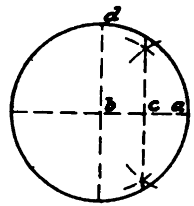


FIG.15.

Problem 3.—To inscribe a regular pentagon within a given circle.

Draw the given circle, using any radius, Fig. 15. Draw a horizontal and a vertical or any two perpendicular diameters. Bisect any semi-diameter, as **b-a**, in point **c**. Using point **c** as the center, with the distance to either end of the other diameter, as **d**, trace an arc from this point (**d**) cutting the horizontal diameter in a point (**e**). Then, with point **d** as a center and the distance **d-e** as a radius, draw an arc from **e** cutting the nearer part of the circumference in point **f**. Arc **d-f** is one-fifth of the circumference. With the dividers, step off this distance carefully about the circle, and then connect in order, the points so located. Extreme care must be taken in each step in the construction of this and of the following problems. Draw light, fine lines; be precise in locating centers; and be exact in stepping off the divisions. The angles of

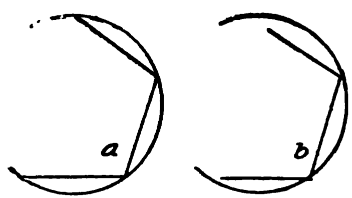


FIG.16.

these polygons must lie precisely in the circumference of the circumscribing circles, as shown in Fig. 16a, not as in Fig. 16b, and their sides must not be "doctored" to make them come out **apparently** correct.

Problem 4.—To inscribe a regular heptagon within a given circle.

Draw the given circle. Draw any diameter, as the vertical one, **a-o.** With either end of this diameter as the center, trace an arc passing through the center of the circle and cutting its circumference in points **b** and **d.** Draw the chord **d-b** cutting the diameter in the point **e.** Then, with point **d** (or **b**) as the center and with **d-e** as the radius, draw an arc from point **e** cutting the circumference in point **f.** Arc **d-f** is one-seventh of the circumference of the circle. Therefore, the chord **d-f** is one side of the required polygon.

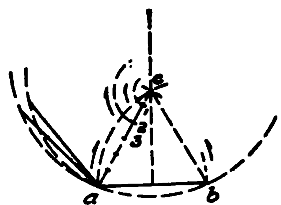


FIG. 17.

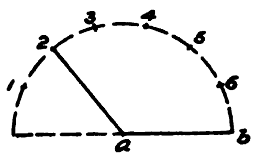


FIG. 18.

Problem 5-6.—To construct regular polygons upon given basis.

(A) Let line **a-b** be the given base (about 1⅛" long), Fig. 17. Construct an equilateral triangle upon **a-b** as a base, by drawing arcs intersecting in point **c,** using **a-b** as the radius and points **a** and **b** as the two centers. Draw and produce the altitude of the triangle indefinitely. Divide a side, as **a-c,** into six equal parts (Prob. 4, Pl. 2). With point **c** as the center, trace arcs from the points on side **a-c** to the altitude produced.

Using, in order, the point **c** and those above as centers and the distances from these centers to either extremity of the base (point **a** or **b**) as the radii, draw circles through points **a** and **b,** these being respectively the circumscribing circles for regular polygons having six, seven, eight, etc., sides and bases of the given length. By this method, such polygons from six to twelve sides may be constructed. The figures here begun are a heptagon and an octagon.

(B) Let line **a-b** be the given base, Fig. 18. Using **a-b** as the radius and either end of the line as the center, draw a semi-circle and divide it into as many equal parts as there are to be sides to the polygon to be constructed. Connect the second point of division on the semicircle with the center, as shown (line **2-a**). Construct the perpendicular bisectors of this line and of the given base, and extend them to their intersection. With this point, **c,** as the center, trace a circle through points **a** and **b.** Step off chord **a-b** on the circumference of this circle, and, joining these points, thus construct the required polygon. The figure here begun is a heptagon.

In inking, remember that fine line work as well as fine lettering give a drawing a fine finish.

Plate 4.

Lettering exercise; lay out; headings.

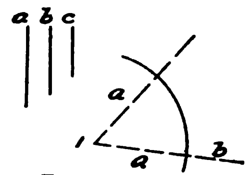


FIG. 19.

Problem 1.—To draw three circles tangent, having their radii given.

Draw, as the given radii, three lines, **a**, **b**, and **c**, Fig. 19. Draw a line, **1-2**, equal in length to any two of these radii, as line **a** plus line **b**. On this line as a base, construct a triangle, making one side equal in length to line **a** plus line **c**, and the other equal to line **b** plus line **c**. With angle 1 as the center (vertex of the angle formed by the sides **a**), trace a circle with the given radius, **a**. In like manner, with the other angles of the triangle as centers, draw circles, using respectively radius **b** at one center and radius **c** at the other. The circles will be tangent in their points of intersection with the sides of the triangle. The curves must just touch, as shown in Fig. 20a, not as in Fig. 20b, nor miss as in Fig. 20c.

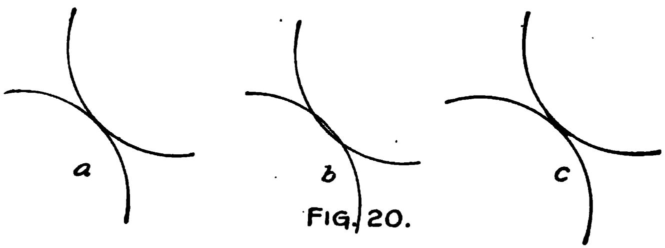


FIG. 20.

Problem 2.—Within an equilateral triangle to draw three circles tangent to each other and to the sides of the triangle. Be extremely careful in the execution of this and of the following problems.

Construct an equilateral triangle (see Prob. 5, Pl. 3). Bisect each angle of the triangle. Extend the bisectors to cut the sides opposite. Bisect either right angle formed by one of these bisectors with the side opposite to the angle which it bisects. The point of intersection (**x**), in which this bisector cuts the bisector of the angle of the given triangle, will be the center for one of the required circles. By means of a circle, the center of which is the center of the triangle, **c**, transfer the center, **x**, just found, to the bisectors of the other angles of the triangle in points **x′** and **x″**. These will be the centers for the remaining two tangent circles required, the perpendicular distance to either adjacent side being the proper radius to use.

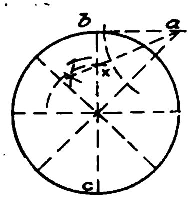


FIG. 21.

Problem 3.—Within a given circle, to draw circles tangent to each other and to the given circle.

Draw the given circle, Fig. 21. Divide the circle by diameters into twice as many equal parts as there are number of tangent circles required. Extend any diameter. Draw a perpendicular at the end of either adjacent diameter (as at end **b** of diameter **c-b**) to its intersection (point **a**) with the extended diameter. Bisect the angle formed at **a**. The point **x** in which this bisector cuts the diameter **c-b**, is the center for one of the required circles. By means of a circle, transfer the center **x** to each alternate diameter, thus locating the centers for the other required tangent circles.

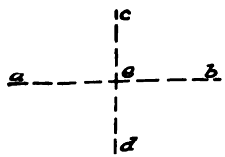


FIG. 22.

Problem 4.—To construct an approximate ellipse upon axes of given lengths.

Let line **a-b** be the given major or longer axis, and line **c-d** the given minor or shorter axis, the two drawn at right angles and intersecting at their centers, **e,** Fig. 22.

Connect the extremities of the axes, as in line **c-b.** With the center in point **e**, using one-half of the minor axis as the radius, from **c** trace an arc cutting the major axis in point **f**. On the line **c-b** set off a distance from **c** equal to the distance **f-b**, that is, one-half the difference of length between the two axes. Bisect the remainder of this line **c-b**, and extend the perpendicular bisector to cut the major and minor axes (the latter produced, if need be) in points **h** and **j** respectively. From **e,** set off on the major axis the distance **e-i** equal to the distance **e-h**, and on the minor axis, **e-k** equal to **e-j**. From **k** draw indefinite lines through points **h** and **i**, and from **j** an indefinite line through **i**. With point **h** as the center, using **h-b** as the radius, trace an arc from the line **j-h**, through **b** to the line **k-h** produced and so continue, using center **k** for the next arc, and then **i**, and center **j** for the arc

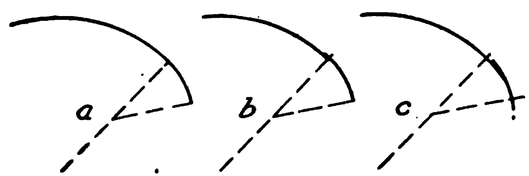


FIG. 23.

completing the figure. The joining of the curves of different radii must be exact, as shown in Fig. 23a, not as in Fig. 23b, or as in Fig. 23c.

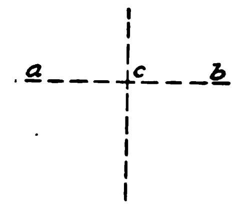


FIG. 24.

Problem 5.—To construct an oval upon a minor axis of a given length.

Let line **a-b** be the given minor axis, Fig. 24. Divide this axis into six equal parts. Then draw and extend indefinitely its perpendicular bisector. Set off on this bisecting line, up from point **c**, a distance (**c-d**) equal to one-sixth of **a-b,** and below point **c** a distance (**c-e**) equal to two-sixths of **a-b**. From the first sixth from each end of the given axis, points **1** (near **a**) and **2** (near **b**), draw indefinite lines through points **d** and **e**. With point **1** as the center, using **1-b** as the radius, trace, through **b**, an arc from **1-e** produced to **1-d** produced. With point **d** as center, continue the curve to line **2-d** produced. With point **2** as center, trace the curve through **a** to line **2-e** produced. Complete the figure, using point **e** as the center.

Problem 6.—To construct an ellipse by revolution of a circle upon any diameter.

If we turn a circle we immediately note a change in its appearance. In the direction in which it is turned it seems diminished. The figure apparent, which might be likened to a flattened hoop, is called an ellipse. No part of its outline is an arc of a circle.

If, in this turning of the circle, we follow the motion of points in its circumference, we can readily trace the figure corresponding to any given position of the circle. In such a figure the longest straight line

possible to draw is the major axis, and the shortest is the minor axis. Let us assume that the major and minor axes are given, lines **a-b** and **c-d** respectively,

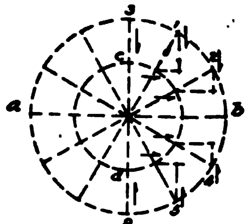


Fig. 25

Fig. 25. Upon each, as a diameter, draw a circle. The larger one we will consider as the unturned circle. Divide it into twelve equal parts by diameters (see Prob. 6, Pl. 1). If, now, we revolve the larger circle about the diameter **a-b** as an axis, the points in its circumference, as **1**, **2**, **3**, **4**, etc., will have the motion (parallel with the short axis) shown by the arrows pointing inward. When the points **3** and **8** have come respectively to points **c** and **d** (the ends of the minor axis), points **1**, **2**, and **4**, **5**, etc., will have moved a proportional distance, as detremined by lines drawn outward (parallel with the long axis) from the points in the circumference of the smaller circle, as shown. Draw a free-hand curve accurately and smoothly through the points thus found. The figure will be the required ellipse.

Supplementary Problems.

At the discretion of the teacher, these are to be used as extra or alternative problems in connection with those of the four preceding plates, and, like those, later, in connection with the problems in working drawings and projections.

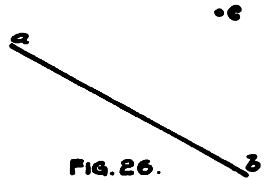


Fig. 26.

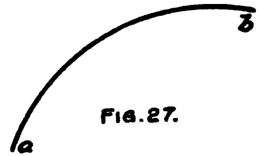


Fig. 27.

Problem 1.—To erect a perpendicular at the end of a given line.

Let **a-b** be the given line, Fig. 26. Assume a point, as **c**, in any convenient position without this line. With **c** as the center and with the distance therefrom to either end of the line (as **c-b**) as a radius, trace an arc greater than a semi-circumference cutting the given line (point **d**) and passing through end **b**. From **d** draw a line through **c** and extend it to intersect the arc just drawn, point **e**. Now, draw a line from **b** through **e**. This is the required perpendicular. In practice, the draftsman would draw this with the triangles.

Problem 2.—To bisect a given arc.

Let **a-b** be the given arc, Fig. 27. Make it of any suitable radius and any length. The solution of this problem is identical with that "To bisect a given line." The bisector of the arc is also the bisector of its chord and of its angle, as experiment will show. If produced it will pass through the center used in tracing the arc. Use this as the test of the accuracy of the work.

Problem 3.—To draw through a given point a line parallel with a given line.

Let **a-b** be the given line, and **c** the given point, Fig. 28. With **c** as the center, and any convenient radius, cut the given line by an indefinite arc in point **d**, as shown. With center **d** and the same radius, pass an arc through **c** and cutting the given line in point **e**.

Taking the distance **e-c** as a radius, use **d** as the center and cut the arc first drawn, in point **f**. Connect **c** and **d**, and draw a line through **c** and **f**. The lines **a-b** and **c-f** are parallel. The angles **c-d-e** and **d-c-f** (called "alternate inferior angles") are equal.

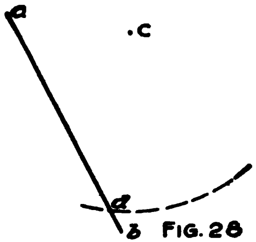


FIG. 28

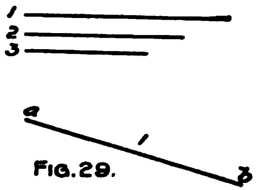


FIG. 29.

Problem 4.—To construct a triangle, its sides being given.

Assume three lines, 1, 2 and 3, as the given sides, Fig. 29. Draw, as a base, line **a-b** equal to 1. With 2 or 3 as the radius, and with end **a** or **b** as the center, trace an arc. With the unused given line as the radius and the other end of the base as the center, draw an arc intersecting the one already drawn in point **c**. This is the vertex of the triangle. Joint point **c** with the ends of the base and thus complete the figure.

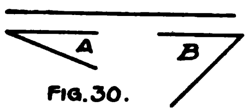


FIG. 30.

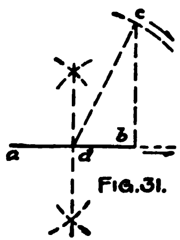


FIG. 31.

Problem 5.—To construct a triangle, two of its angles and the included side being given.

Let **A** and **B** be the given angles, Fig. 30. Preferably make them acute angles. Assume as the given side a line of any convenient length. As a base, draw the line **1-2** equal to the given side. At the end of this construct an angle equal to the given angle **A**, and at the other end construct an angle equal to the given angle **B**. For this, use the method explained in Prob. 3, Pl. 1. Extend the side of each angle without **1-2**, indefinitely. These sides will intersect, thus completing the triangle.

Problem 6.—To construct a regular pentagon upon a base of a given length.

Let the line **a-b** be the given base, Fig. 31. Erect a perpendicular at either end, **a** or **b**, making it equal to **a-b**. Bisect **a-b** in point **d**. With **d** as the center, trace an arc from **c** (the upper end of the perpendicular), cutting the given base extended, in point **e**. With **a** as the center, trace upward an arc from **e** using **a-e** as the radius; with **b** as the center, cut the arc just drawn in point **f**, using this same radius. Now, with point **f** as the center and a radius equal to the given base, **a-b**, trace an indefinite arc across the figure and below **f**. With the same radius (**a-b**) and with **a** and **b** as centers, cut this arc in points **g** and **h**. By connecting points **a**, **g**, **f**, **h**, and **b** in the order named, the figure will be completed.

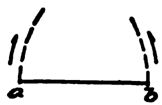


FIG. 32.

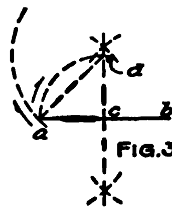


FIG. 33.

Problem 7.—To construct a regular hexagon upon a base of a given length.

Let a-b be the given base, Fig. 32. With a and then b as the center and with a-b as the radius, draw arcs intersecting in point c. With c as the center and with radius c-a or c-b draw a circle passing through a and b. The base a-b can be set off upon the circumference of this circle six times. As c-b equals a-b, the radius of any circle equals the chord of one-sixth of its circumference.

Problem 8.—To construct a regular octagon upon a base of a given length.

Let line a-b be the given base, Fig. 33. Bisect the base in point c and extend this bisector indefinitely. With c as the center, trace an arc from a or b, cutting the bisector in point d. With d as the center, trace an arc from a, cutting the bisector in point e. With e as the center, pass a circle through the ends of the given base, a-b. The base a-b is the chord of one-eighth of this circle.

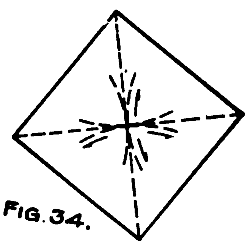


FIG. 34.

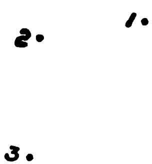


FIG. 35.

Problem 9.—To inscribe a regular octagon within a square.

Construct a square and draw its diagonals, Fig. 34. Then, with each angle of the square as the center, and with a semi-diagonal as the radius, trace arcs cutting the sides of the square adjacent to the centers used. Connect the points thus found so as to cut off the cor-

ners of the square. These lines will be the sides of the octagon. The alternate sides of the octagon will coincide with the sides of the square.

Problem 10.—To draw an arc through three given points.

Assume any three points, as 1, 2, 3, arranged other than in a straight line, Fig. 35. Join 1 and 2, 2 and 3. These straight lines are chords of the required arc (see Prob. 2 of this set). Bisect them and produce the bisectors to their intersection in point c. This is the center sought. With a radius to any of the points, trace an arc. It will pass through the other points.

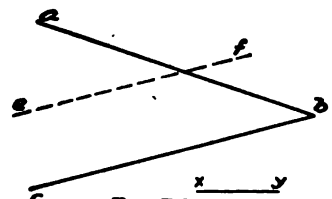


FIG. 36.

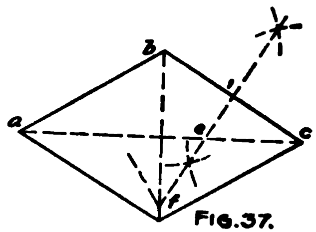


FIG. 37.

Problem 11.—To draw within a given angle a circle of a given radius, tangent to the sides of the angle.

Given the angle a-b-c, Fig. 36. Assume line x-y as the given radius of the circle to be drawn. Bisect the angle b through line b-d. The center of the required circle must lie in this line. A tangent is perpendicular to the radius drawn to the point of tangency. If then, at a distance from one side of the angle equal to the given radius (x-y), a line, e-f, be drawn parallel with that side, and cutting the bisector of the angle, the point thus found, will be the center of the circle required.

Problem 12.—To inscribe an approximate ellipse within a rhombus.

(A rhombus is a quadrilateral whose sides are equal and whose opposite angles are equal.)

Draw a rhombus, as **a-b-c-d**, of any suitable size, Fig. 37. Bisect each side, as in points **1**, **2**, **3**, and **4**. Produce these perpendicular bisectors to their intersections with the diagonals of the rhombus, in points **e**, **f**, **g**, and **h**. These are the centers required. With a radius from each center to the ends, **1**, **2**, **3**, **4**, of the corresponding bisectors, trace the arcs between these bisectors and tangent to the sides of the rhombus, thus completing the problem.

Definitions of Geometric Terms.

Before entering upon the subject of Working Drawings, we will give some attention to the definitions of the various common geometric solids with which we are about to deal.

Solids.—A solid is that which has three dimensions.

Polyhedrons or plane surface solids: Any solid bounded wholly by planes is a polyhedron. Its edges are the lines of intersection of its bounding planes. Its faces are the plane figures formed by its edges.

A prismatic surface is a surface formed by passing planes through successive pairs of parallel lines.

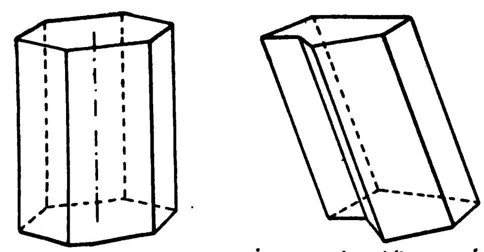


FIG. 38

Prisms: A prism is a polyhedron bounded by a closed prismatic surface and two parallel planes called bases.

The axis of a prism is the imaginary straight line joining the center of its bases, these centers being the centers of circles inscribed in the bases, when possible. If its axis is perpendicular to its bases it is a right prism. If otherwise, it is an oblique prism.

If the bases of a right prism are regular polygons, it is a regular prism. Any other prism is irregular.

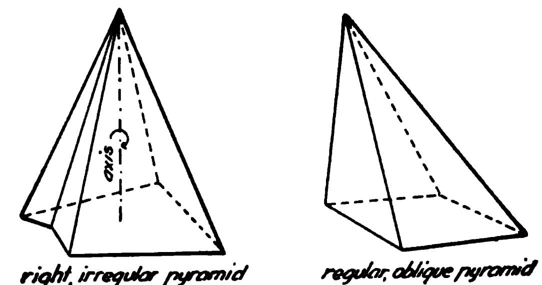


FIG. 39

Pyramids: A pyramid is any polyhedron having a polygon for its base and triangles with a common vertex for its sides.

The axis of a pyramid is the imaginary straight line from its vertex to the center of its base, this center being the center of the circle inscribed in the base, when possible.

If its axis is perpendicular to its base, it is a right pyramid. If otherwise, it is an oblique pyramid.

If its base is a regular polygon, it is a regular pyramid. Any other pyramid is irregular.

Pyramids and prisms are named from the shapes of their bases, as triangular, square, hexagonal, etc.

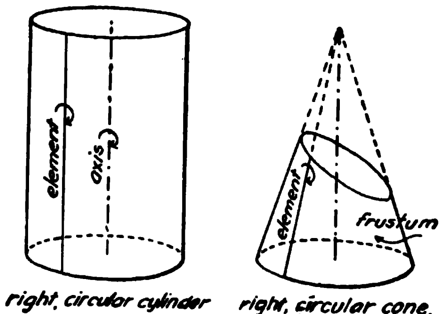


FIG 40.

Curved surface solids: Cylinder:—The surface described by the movement of a straight line about a curve without change of direction (i. e., always remaining parallel with a fixed straight line and passing through a fixed curve) is a cylindrical surface. A cylinder is a solid bounded by a closed cylindrical surface and two parallel planes, the bases. The common kind, the right, circular cylinder, may be considered as resulting from the revolution of a rectangle about one of its sides. It resembles a prism, excepting that its bases are circles.

The side about which the rectangle was revolved becomes the axis or center line of the cylinder.

Any straight line in the cylindrical surface is an element of that surface. All elements are parallel with the axis.

Cone: The surface described by the movement of a straight line, one end of which is fixed, while the other follows a curve, is a conical surface. A cone is a solid bounded by a plane and a closed conical surface. The common variety, the right circular cone, may be considered as resulting from the revolution of a right triangle about one of the sides adjacent to the right angle.

It resembles a pyramid excepting that its base is a circle.

The side about which the triangle was revolved becomes the axis or center line of the cone.

The vertex of the triangle becomes the vertex of the cone.

Any straight line from the vertex to the base is an element of the conical surface.

Sphere: A sphere is a solid bounded by a curved surface all points of which are equidistant from a point within called the center. This spherical surface may be considered as resulting from the revolution of a circumference about any diameter.

Truncate: The process of cutting off the top of a solid, as of a prism, a cone, etc. See Fig. 40.

Frustum: The part of any solid remaining after the top has been cut off, as at a cone, a pyramid, etc. It always contains the base of the solid. See Fig. 40.

Working Drawings.

Working drawings are those conventional representations intended to show clearly and completely the shape, the dimensions (in detail and in general), and the arrangement of parts in an object to be made, accompanied by such explanations and directions as are needed in its making and finish.

Although from an ordinary pictorial representation of an object certain general peculiarities of its form and structure may be readily understood, yet the precise facts of proportion and of construction necessary to its making are lacking. Usually, in such a drawing, its edges and its dimensions are not shown in their true relations, nor its surfaces in their true shapes, while its internal construction may not be evident at all.

If, however, the imagined object be pictured, both visible and invisible parts, upon two or more surfaces assumed in positions parallel respectively with its several dimensions (its length, its breadth, and its thickness), the views thus shown will give the information needed for its manufacture.

Views.—Two such views are always necessary (more are often needed), one taken directly from above, called the "top view," and the second taken directly from in front, called the "front view," the latter of these being always drawn directly below the former. When a side view is used to show more fully the facts of the object, it is drawn directly to the right of or to the left of the front view.

Lay Out.—Fig. 41, working drawing of a hip roof, and chimney.

In the illustration, first, the axes or center lines of the three views were drawn. Then, symmetrically upon these, the top, the front, and the side views were constructed and in the order mentioned. Thereafter, the views were inked and "shadow lined," dimensioned and named, the scale to which they were drawn stated, the title or heading printed and the border line drawn. This is the usual order of procedure for the pupil to follow in his work.

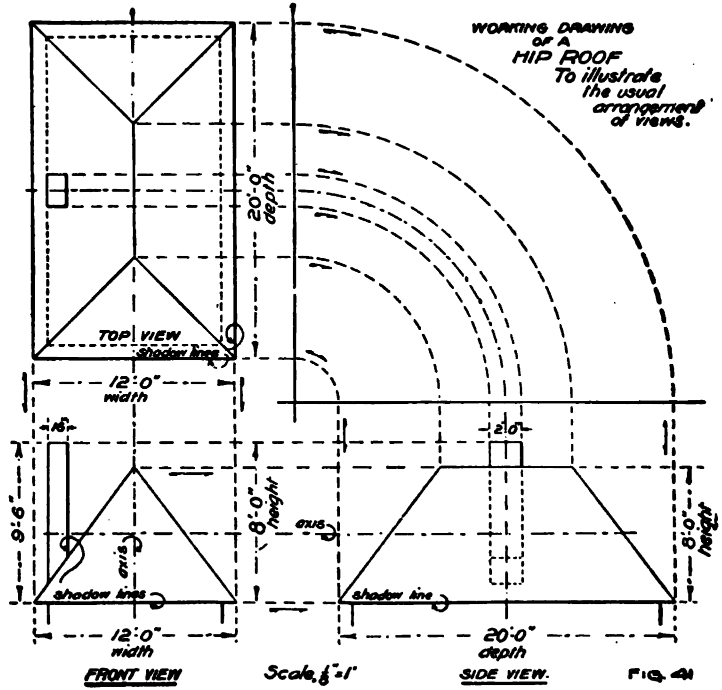


FIG. 41

In the figure, notice: That each of the three views of the object is very different from the other two.

That from all three together, a much better understanding of the object is secured than from any two of them, and that no one view shows enough facts to make possible the object's construction.

That the invisible as well as the visible parts are drawn, the former in dotted lines, and that what is visible in one view may be hidden in some one of the other views.

That the top view shows width (distance from left to right) and depth (distance from front to back).

That the front view shows height and also width.

That the side view shows height and depth.

That each dimension of the object appears in two views of it, and that each view presents two differing dimensions; hence, if these facts of an object are known, by combining them correctly the views of it may be laid out directly and independently of each other. Or if any two views are laid out, the third view may be found by carrying from the views already drawn the unlike dimensions, and combining them.

If, in Fig. 41, the side view is to be found from the two others, the height is carried over from the front view, and the depth is swung about from the top view, and combined with the height, as shown, the center for this revolution being located wherever convenient.

Data.—The facts of proportion and of structure of objects, when obtained or calculated, may be recorded as written description only, as pictorial sketches illustrative of and accompanied by description, and as dimensioned free-hand working sketches with specifications attached.

Invariably, working drawings are made from such notes or records, which are always necessary if the objects are at all complex, as are articles of furniture, machinery, buildings, etc.

In these several ways the problems will be presented in this text in order that thereby the pupil may become familiar with practical methods.

The problems will comprise a "statement," usually, but not always, accompanied by a "specification for laying out," and "suggestions for solution" where needed.

Scales.—Working drawings are constructed either "full size" or "to scale." In the first case, the drawing is the actual shape and of the actual dimensions of the object or part. In the second case, while the actual shape is shown, the dimensions are less than actual, but are at a stated ratio to the actual, usually expressed in "inches per foot," which means that each inch or certain fraction of an inch of dimension in the drawing is the equivalent of one foot in the structure or "on the ground," as 1½″ equals 1′, or ¼″ equals 1′, etc.

On the implement, the scale, the units of the scales (⅛″, ¼″, ¾″, etc.) when large enough to permit of it, are divided into twelve equal parts in order that, by this means, inches may be laid off on the drawing in the proper proportion.

The scale to which a drawing is made must always be stated.

Here the pupil should begin his work, Plate 5, referring to the following paragraphs on Inking, Dimensions, and Titles when directed, as his work advances.

Inking.—In inking working drawings, all visible edges of the objects are made with solid lines, while invisible edges are indicated by dotted lines. The construction lines drawn from view to view are inked "dashed." Ink the extension and dimension lines after the views have been inked and the dimensions inserted. See Fig. 11.

If, in each view of the object, the right and the lower outlines (when these are not edges common to two visible faces) are made heavier than the other

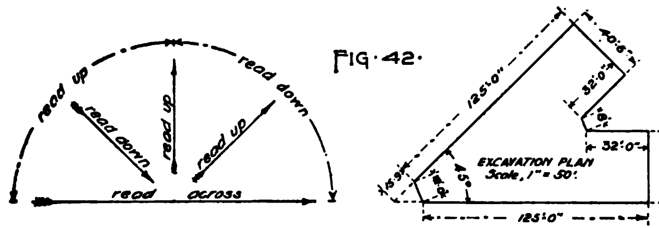
outlines, an effect of shadow is produced which strengthens and much improves the appearance of the drawing. These are called "shadow lines," and the process is termed "shadow lining." See Fig. 41. Do not shadow line developments.

Dimensions.—Generally, the pictures of an object, such as are shown in a working drawing of it, are not, in themselves, sufficient for the making of the object, even though the scale of the drawing is stated. Although these representations show the arrangement and the relative proportions of its parts, etc., they are incomplete and of little practical use as working drawings until, upon them, the precise dimensions of the object, as a whole and in part, are fully marked. The workman must not be left to "scale" or to guess at the dimensions of any important or specially designed parts.

If the fact is kept in mind that every form and its every part have three dimensions, the process of dimensioning will be readily understood. It is evident that somewhere upon the drawing each of these dimensions must be shown at least once. Dimensions should be put only upon distances, linear and angular, which are shown in truth.

The points between which measurements are taken must be clearly indicated. When, as is usually best, the dimensions can be placed wholly outside of the drawing, these points are shown by the use of parallel "extension lines" drawn squarely outward therefrom. Then, perpendicularly between these extension lines, the dimension lines are drawn and the dimensions are inserted, at their centers, if possible. The extension and dimension lines are generally drawn in red ink to distinguish them from the lines of the object, the extension lines being "dashed" and the dimension lines "dot and dash," or often, to save time, being made solid, broken only for the dimension.

To emphasize the initial points of measurement, black arrow-heads are made at the ends of the dimension lines.



FIG·42·

Dimension and extension lines should be drawn so as to conflict as little as possible. And, because of their importance, the figures of dimension should be perfectly legible and so printed that they may be read without inverting the drawing. Fig. 42 shows the ways in which the figures should read, assuming the horizontal as the lower edge of the drawing.

Titles.—Although on shop drawings there is seldom much time spent in the making of elaborate titles and of ornate border lines, yet these particulars should always be executed tastefully, no matter how simple they may be, in order that the work may be given a pleasing finish.

The title should be placed where it seems to be needed to maintain the balance of the work on the plate, and not, as an afterthought, be "just slapped in anywhere."

In the design of titles, the statements should be compactly grouped in order that they may be read at a glance. Do not string them out across the plate. Generally, for titles, use vertical letters in preference to slant letters. Do not combine incongruous styles

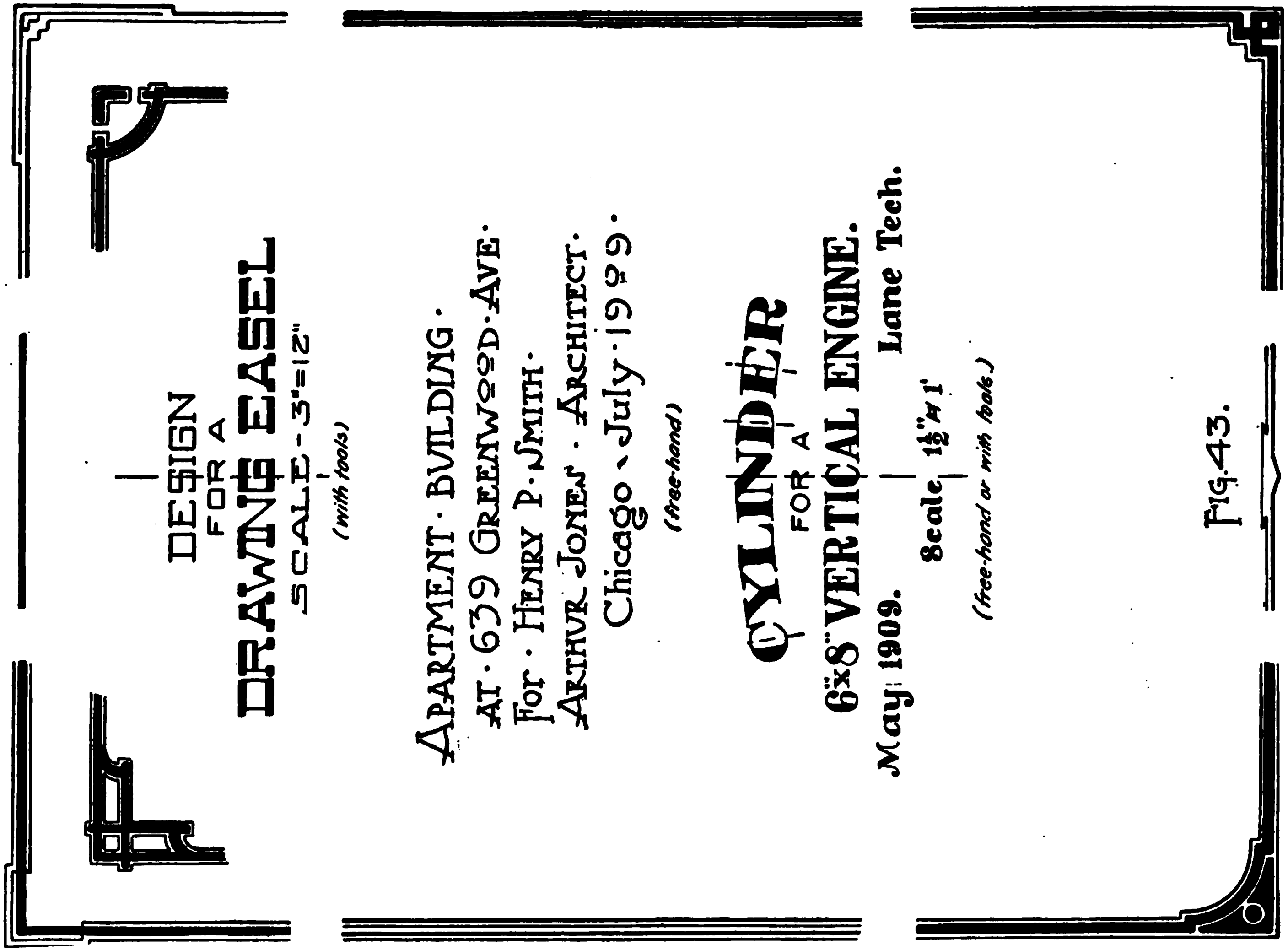

DESIGN
FOR A
DRAWING EASEL
SCALE - 3"=12"
(with tools)
APARTMENT · BUILDING ·
AT · 639 GREENWOOD · AVE ·
FOR · HENRY P. SMITH ·
ARTHUR JONES · ARCHITECT ·
Chicago · July · 1909 ·
(free-hand)
CYLINDER
FOR A
6"x8" VERTICAL ENGINE.
May 1909. Lane Tech.
Scale 1½"=1'
(free-hand or with tools)

Fig. 43.

in a title or on the drawing, such as very heavy and fancy letters and light, plain ones. Also, for like parts of a drawing, and for a set of drawings of the same subject and kind, the titles and general lettering should be uniform in style. In many offices, a set form of title is stamped or stenciled upon the drawings to secure uniformity and to save the draftsman's time.

Emphasize the important statements by larger letters or by stronger treatment, and subordinate the less important ones.

Before working out the title upon the drawing, it is often well to sketch it elsewhere, experimentally, to determine the best size and style of letters and the best arrangement for the various rows of words. When these rows of words are centered upon a common vertical axis, as shown in Fig. 43, begin with the middle letter of each row and work both ways. Of course, such designing is best done in pencil first and inked later.

Do not try to make showy or elaborate border lines having more interest than the drawing itself, perhaps; keep them simple and appropriate. Fig. 43 gives a few suggestions for the design of titles, of border lines and of corners. Only occasionally are these latter called for.

Plate 5.

This plate will be given wholly to a careful duplicating of Fig. 11, "Examples of Lines and Their Uses," the printing to be executed free-hand.

This is to be done on a sheet of the regular drawing paper, the plate to be of the same size as the previous ones, 9½"x15".

The exercise comprises the title, the statement of uses, and the examples of lines.

The alphabet used shall be the Shop Skeleton, slant or vertical. The necessary base lines for the rows of words shall be 5/16" apart. The length of the rows of words shall be approximately uniform. The examples of lines shall be ⅜" apart. The vertical axis of the mass of printing shall coincide with that of the plate.

The height of the small letters shall be ⅛" and the height of the capitals shall be proportioned properly thereto; see Fig. 5.

A slightly ornate border line may be attempted, if wished.

Work for correct shape and uniform slant of letters, and for good spacing of letters and of words. Do one sheet in pencil, as an experiment, then try doing a second directly in ink. The bookkeeper does not first write in pencil and then trace over his writing with a pen.

To facilitate his work as a draftsman, the pupil must acquire the ready use of the pen in lettering.

Text of Problems.

Of the seven following plates, the pupil must do, to secure his year's credit in the subject, besides the lettering exercises called for later, Plates 6, 8, and 11, and any two of the others that the teacher may assign. For the experience to be gained, he should try to do them all.

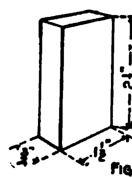


FIG. 44.

Plate 6.

Problem 1.—A rectangular prism with development.

Make a working drawing of the rectangular prism shown in Fig. 44.

Evidently, each view of this prism will be a rectangle, and yet it is also evident that no two of these views will be alike. Hence, to show all its appearances, the top, the front, and the side of the prism should be drawn. As the prism is small, these views may be drawn the full size of the faces. The object is assumed as upright with its wider face to the front.

Now, how should the views be arranged? Note, in Fig. 41, that, as before stated, each two adjacent views (such as the front and the top or the front and the side views) have one center line or axis the same —i. e., in common. By thus centering the views on a common axis, their like points will fall more readily into the right relation, as shown by the dotted construction lines in Fig. 41; those marked with an arrow. Therefore, in this and later problems, locate these center lines first, and then construct the views of the objects upon them.

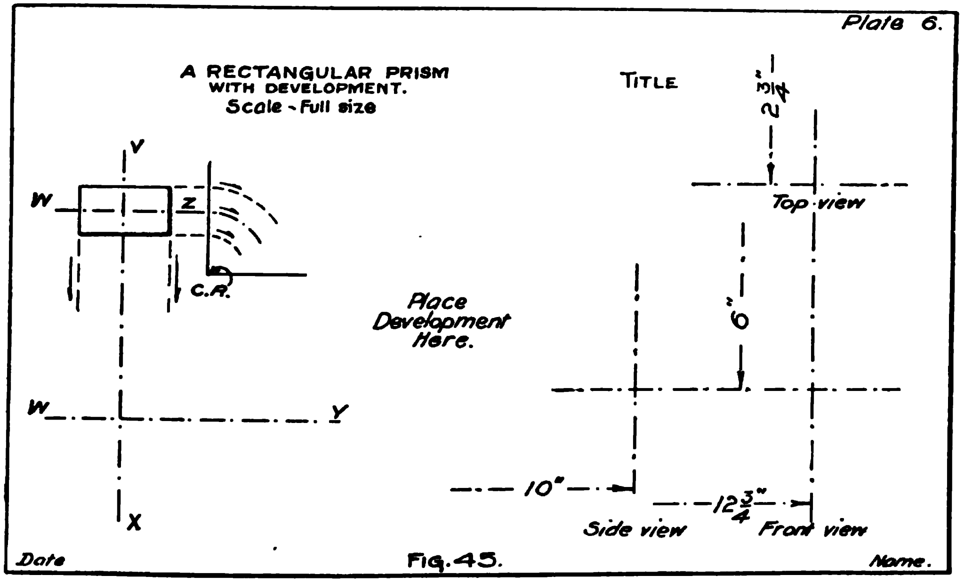


Fig. 45.

Location.—Fig. 45. Where convenient, in this case, 1¾″ to the right (R) of the left border line of the plate and parallel therewith, draw a line, **V-X.** Assume this as the common axis for the top and the front views. Unless otherwise directed, the top view

or plan should always be drawn first, when this is possible. The top view of the prism is a rectangle ¾″ by 1½″, and, in accordance with the assumed position of the prism, the longer sides of this rectangle should be horizontal. With its center line of width, **W-Z,** 3¼″ down (D) from the upper border line, let us construct this rectangular top view, drawing one-half of it on each side of the vertical axis.

From a point 6½″ D, measured on the vertical axis, draw a horizontal line, W-Y. This will be the common axis for the front and the side views.

With the triangle and tee square, carry down the width of the prism from the top view, as indicated. Then set off one-half of the height of the prism (1¼″) above and below this horizontal center line just drawn, and so construct the front view.

Again referring to Fig. 41, note how, by revolution, the depth in the top view is carried about and down, and combined with the height carried across from the front view, to work out the side view. In like manner, construct the side view of the prism, assuming the center for the revolution, C. R., 3⅛″ R. and 4¼″ D.

In order to show the relative positions of all corners of the prism in all views, number or letter them, always giving the same name to each point in all views, as illustrated in Fig. 46. To prevent confusion of points, the pupil should make it a practice to do this with all problems.

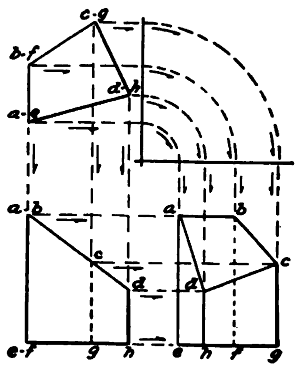


FIG. 46.

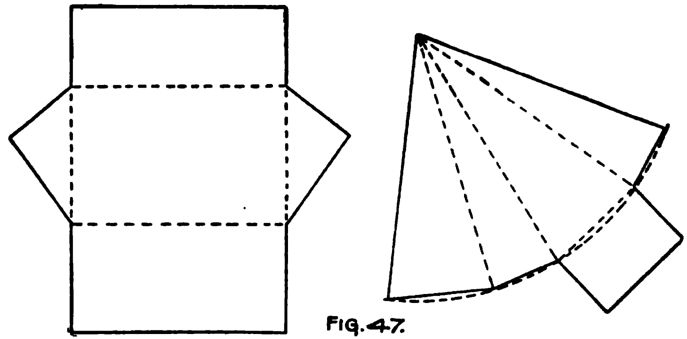


FIG. 47.

Development.—Frequently the extent of surface of an object is desired, requiring that a diagram of its faces be laid out, giving what is called a "development" or unfolding. In this, the several surfaces should be arranged in accordance with their relative positions in the original object—i. e., those that are next to each other in the object must be so placed in the development. Fig. 47 shows the development of a right triangular prism and of a right, rectangular pyramid.

In the space to the right of the views just drawn, after completing the second problem, lay out a development of the rectangular prism.

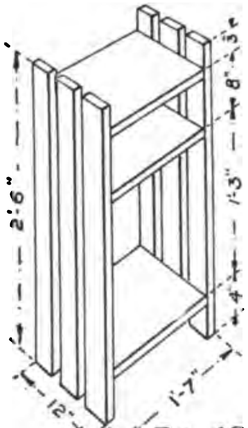


FIG. 48.

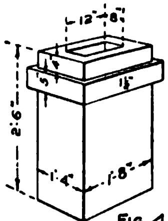


FIG. 49.

Problem 2.—A rectangular magazine rack.

Make a working drawing, showing three views of the simple magazine rack illustrated in Fig. 48. All parts are 1" in thickness. The side strips are 3" wide. The front view is to show width and height. Scale, 1½" equals 12"; see paragraph on Scales, page 26. . .

Note.—The brick chimney shown in Fig. 49 may be substituted for this magazine rack, if desired.

Location.—Proceed in exactly the same way as that followed in working out the previous problem.

The axes for the several views are to be located where shown in the location chart, Fig. 45. Construct the side view directly from the dimensions given, and not by revolution, as was done in Prob. 1.

Before inking, read the paragraphs on this subject, page 26. Note that, in the side view of Prob. 2, the shelves are, in part, invisible; hence such parts should be indicated by dotted lines. Also, using dashed lines, ink the construction lines extending from points in one view to like points in the other views. Design a neat title for each drawing. Include the scale in this.

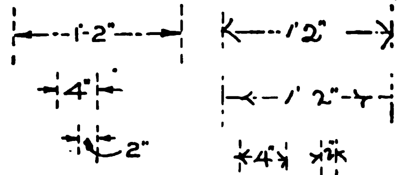


FIG. 50.

Before dimensioning the views, read the paragraph on the subject, page 27. Keep the dimension lines ¼" or more from any view; give all necessary dimensions for the construction of the object, but do not repeat them needlessly; make the figures of dimension of good size and perfectly legible; make arrow heads as shown in Fig. 50a, not as in Fig. 50b. Remember that your drawings always should be so clear and so complete in their information that they would be understood perfectly by the workman in making the objects represented.

Lettering Exercises.—Too much emphasis cannot be put upon the fact that skill in free-hand lettering is a necessity to the draftsman. This he can acquire only by much and careful practice. The plates of working drawings, aside from the titles and dimensions, require but little lettering. Hence, a lettering exercise of fifty words, to be done on the prepared lettering paper at other times than the drawing periods, will be required with this and with each of the succeeding plates.

Besides the alphabets and the numerals, the selections to be printed are the important explanatory

paragraphs, the definitions, etc., from the introductory text, at the direction of the teacher.

The practice should be upon one alphabet only, until that is mastered. Of these, the Shop Skeleton is the most generally serviceable.

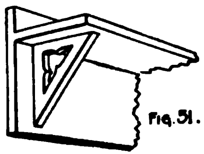


Fig. 51.

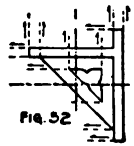


Fig. 52

Plate 7.

Problem 1.—A rectangular shelf.

Make a complete working drawing for a simple shelf from the accompanying sketch, Fig. 51, and the following description:

The shelf is 2′ long, 9″ wide and 1″ thick. It is attached to a back or wall piece 2″ below the upper edge of the latter. This is 2′ by 1′ and 1″ thick. The shelf is supported by two right triangular brackets, each 8″ by 8″ by 1″. These brackets are set 1½″ from the end of the shelf. The shelf is horizontal, with the brackets visible in the front view. Scale, 1″ to 6″. Use for this, the scale 1″ to 1′, doubling the readings.

Location.—To begin with, as in the previous problems, draw the axes where specified. In the side view, the axes of width and of height intersect 6½″ R. and 6⅝″ D. In the front view, the axes of length and of height intersect 2½″ R. and 6⅝″ D. From these two views, find the top view, assuming the center of revolution to be 5″ R. and 4¼″ D.

First, as shown in Fig. 52, construct the side view where required. From this side view carry across the levels of the various parts as shown; and by setting off the length of the shelf and of the back, and the position of the brackets, complete the front view in the location fixed by the axes already drawn.

Now, from the side view, carry up and revolve the width of the shelf, the outer ends of the brackets, etc. Then, from the front view, carry up the length of the shelf and the back and the position and thickness of the brackets, thus working out the top view. In the top view, the brackets are invisible; hence are to be inked accordingly.

Note.—The brackets and the back may be made ornamented in a simple way, if desired, and the pupil is encouraged thus to add variety and attractiveness to his work.

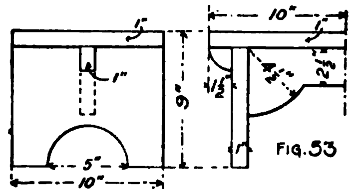


Fig. 53

Problem 2.—A rectangular stool.

Note.—A knife box, a desk book-rack, or a like object of equal difficulty, may be substituted for the problem here given, at the discretion of the teacher. It is suggested that the pupil submit a simple design for some one of these articles, and that he then make a working drawing therefrom.

Make a complete working drawing for the rectangular stool from the given, dimensioned working sketch, Fig. 53.

Notice that, in the figure, only one-half of the front view is shown. The pupil is to draw the whole stool. Scale, 1″ to 6″. The stool is horizontal, with both supports visible in the front view.

Location.—The axes intersect in the top view, 12¾″ R. and 3″ D.; in the front view, 12¾″ R. and 6⅞″ D. The center of revolution for the end view is 10⅜″ R. and 4½″ D., the revolution to be to the left. Draw the axes of arrangement, then the top, the front, and finally the side view.

In inking, shadow-line and dimension the views as before, showing all invisible parts by dotted lines.

Plate 8.

Problem 1.—A flight of steps from a model.

(Left one-half of the plate.)

The pupil is to make, in shop perspective, a dimensioned, free-hand sketch of a flight of three or more steps from the school room model. See note below.

This sketch is to be made as preparation for the class work at other time than the drawing period. From this sketch a working drawing of the object, showing three views, is to be made in class.

A suitable scale, the proper location of the axes and of the views, is to be determined by trial, by the pupil. The sketch is to be drawn in the upper left hand corner of the plate. It is to be inked and dimensioned.

For most of the plates, in order to assure good placing of the work, and also to save the pupil's time, the locations of the problems are specified. In these the positions of the views are fixed by locating their axes. In like manner, the pupil should fix the positions of the views in problems for which no specifications are given—i. e., by drawing the axes for the views first.

It is not well for the pupil to become dependent upon "full specifications" for laying out his work, nor upon "full explanations of solutions." Hence, wherever particulars of this kind are lacking, he is expected to rely somewhat upon his own knowledge and judgment as to "what to do" and "how to do it."

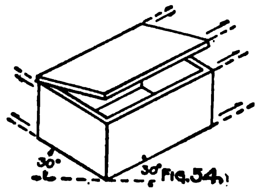


Fig. 54.

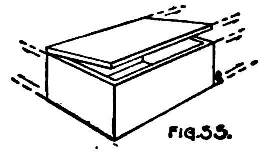


Fig. 55.

Note.—In shop perspective the retreating parallel edges of the object are drawn parallel and not approaching, as they retreat, as is the case in true perspective. Also, in rectangular objects like this one, the retreating edges are often drawn in their true lengths instead of fore-shortened—i. e., instead of diminished because turned away. Frequently these are termed "isometric sketches," isometric meaning "of equal measures." Such sketches are easily made by using the 30 degree triangle as shown in Fig. 54. Notice the difference between Fig. 54 and Fig. 55, a box drawn first in shop perspective and then in true perspective.

Problem 2.—A waste box or similar school room object.

The pupil is to prepare a sketch as in the previous problem, and to make a complete working drawing of the object therefrom, also showing the sketch, as before.

Plate 9.

Problem 1.—A right circular cylinder from the pupil's sketch.

The pupil is to make a working sketch from the object and a working drawing from the sketch. A working sketch is simply a working drawing made free-hand, and to no definite scale.

Notice that, in this problem, the side view is unnecessary, as it is the same as the front view and so presents no additional facts. Make the cylinder full size, diameter 1¾″, length 2½″, axis vertical.

Location.—The top view is a circle. Place its center 1¾″ R. and 3½″ D. In the front view the lower base is 8″ D.

In the space between this problem and Prob. 2, after the latter is done, lay out the development of the cylinder. Allowance for this development must be made in placing the second problem. By experiment with a piece of paper the pupil will discover that the development of a right cylinder is a rectangle. The width of this rectangle is the height of the cylinder. To obtain the length, set off, as a unit, the chord of one-twelfth of the base of the cylinder, twelve times, taking this chord from the top view. See Pl. 1, Prob. 6. Complete the rectangle and attach the bases.

Problem 2.—A caster.

Note.—The cylindrical wall pedestal shown in Fig. 59, or the cast iron bracket shown in Figs. 60, 61, may be substituted for this, if desired. Descriptions below.

The Caster.—Make a complete working drawing of the caster, from the side view, Fig. 56, and the description. Scale, *full size.* The sketch, Fig. 57, gives the thickness of the fork, and its opening. The width of the tread or cylindrical surface of the roller is 1″.

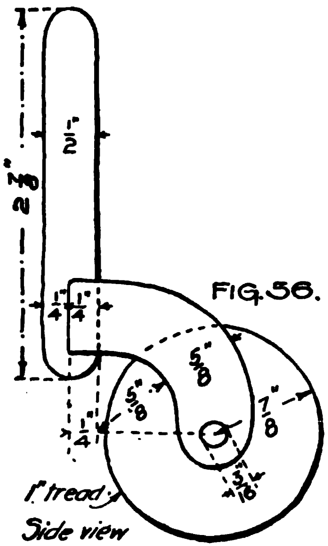


FIG. 56.

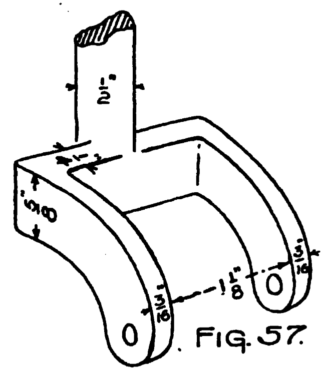


FIG. 57.

Location.—Draw the side view, and from it obtain the others. Place the center of the roller in this view 7⅜″ D. and 10⅝″ R.; the roller to the right, as shown in the figure. The location of the other views the pupil is to determine.

The drawing is to be dimensioned and shadow-lined, as usual. To shadow-line a circle, draw two diameters at 45 degrees, Fig. 58. Set the center for the shadow-line arc down to the right of the center of the circle a distance equal to the extreme width of the shadow-line. With the same radius as that of the circle, using the center (c′), draw a semicircle on the other diameter, below, and to the right, to show an

outside cylindrical surface, and above and to the left, to show an inside cylindrical surface, as shown in the f gure.

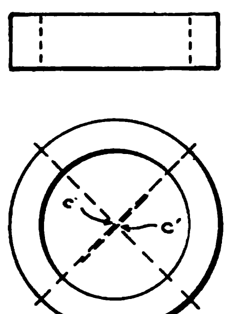


FIG. 58.

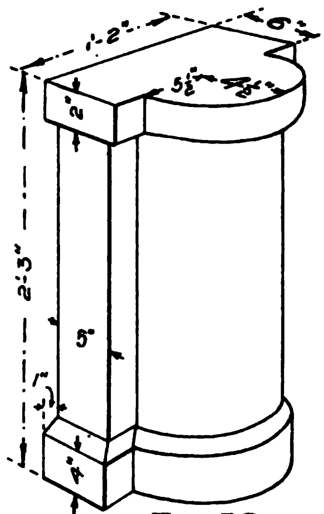
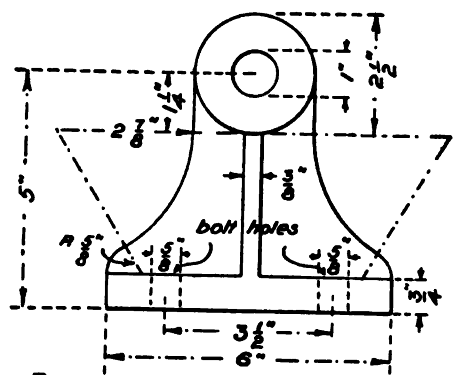


FIG. 59.

The Pedestal.—The top and base of the pedestal each project 1″ beyond the shaft at the front and at the sides, but not at the back. The cylindrical parts are less than one-half of a cylinder. The center and the radius for the cylindrical portions must be found from the dimensions given, by the method given in Supplementary Prob. 10. The whole base is 5″ high; the face 4″, the slope of its upper edge being at 45 degrees. All other dimensions are given in the sketch, Fig. 59. The front is to show in the front view. Locations of the views to be determined by the pupil. Scale, 1½″ to 12″.



Bottom view. FIG. 60.

The Wall Bracket.—The facts of this object are given in a **bottom view** and in a sketch. The bottom view shows the appearance of the object as looked at from beneath. Draw this view, placing its lower outline 8″ D. and the vertical axis of the view 12⅞″ R.

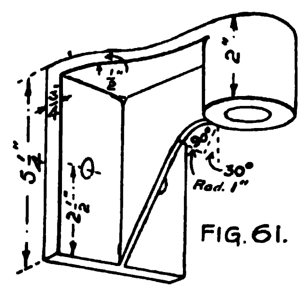


FIG. 61.

The front view will be drawn **above** this view in the same way that such a view is drawn **below** a top view. From this bottom view and the additional information given in the sketch, complete the front and side views, the latter being placed directly to the left of the front view, as is usual. Scale, one-half full size.

Plate 10.

Problem 1.—A regular pentagonal pyramid.

Make a working drawing of a right, vertical, regular pentagonal pyramid having an altitude of 3¼" and a base inscribed in a circle of 1⅛" radius. See Prob. 3, Pl. 3.

The pyramid is to be so placed that an angle of the base is at the back, and so that, in the front view, three of its lateral faces, or sides, are visible, two equally each side of the third, the middle one.

Draw the top, the front, and the side view, and the development or pattern of the pyramid. Scale, full size.

Location.—The vertex in the top view is 1¾" R. and 2½" D. In the front view, the base is 8¼" D. The center of revolution for the side view is 3¼" R. and 3¾" D. The vertex in the development is 6¼ R. and 2¼" D. From this point draw a vertical line downward, making it equal in length to the rear, lateral edge of the pyramid, as shown in the side view. This line is the true length of all the lateral edges—i. e., those from the vertex to the base. It will be the left side of the development. Using it as a radius and its upper end, the vertex, as center, draw an arc of indefinite length. On this arc set off the length of one side of the base (taken from the top view) five times, and join the consecutive points. Also connect them with the center used. Then attach the base. This is the method used in laying out the development of all regular pyramids.

Problem 2.—A street lamp. Fig. 62.

Note.—The garden flower-box shown in Fig. 63 may be substituted for this object. Also a pyramidal waste basket, a lamp shade, or a tile chimney top might be used in its stead.

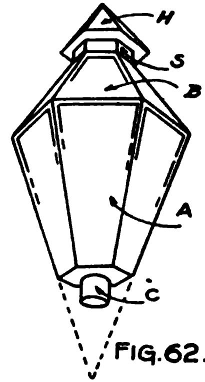


FIG. 62.

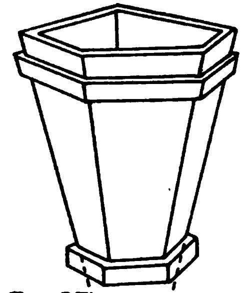


FIG. 63.

The Street Lamp.—The lamp is made up mainly of two regular hexagonal pyramids having a common base, the longest diagonal of which is 1′ 7″. The altitude of the inverted pyramid (**A**) is 2′ 3″; that of the upright pyramid (**B**) is 9″. The top of the former is cut off (truncated) 1′ 5″ from its base by a plane parallel therewith. In like manner, the latter is truncated 6½″ from its base. A circular collar (**C**), 3″ in diameter, projects 3½″ below the lamp. The portion of (**S**) supporting the hood (**H**) is 1½″ high. The altitude of the hood is 3″. The long diagonal of its base is 7″. Draw three views. Scale, 1½″ equals 12″.

Location.—Three faces of each pyramid are to be visible in the front view, two equally each side of the middle one. Draw the top view of the two main pyramids first. This will be a regular hexagon. See Supplementary Prob. 7. Place the center of the hexagon 2½″ D. and 12¾″ R. The pupil will determine the position of the other views. Draw the diagonals. These will represent the lateral edges of both pyra-

mids. Next, draw the front view of the two large pyramids complete, and truncate them where and as directed. Add parts **S** and **C** in this view and indicate these parts in the top view. Now draw the top view of the hood and then its front view. Finally, from these two views of the lamp, obtain the side view. In this latter, only two faces of each pyramid will appear and these will be equal.

The whole front view and one-half of the top view are given, as shown in the accompanying location plate, Fig. 64. The top view is to be completed and the side view is to be found. In the front view, the axes intersect, 2½″ R. and 6½″ D. The long axis of the prism is inclined at 60 degrees left to a horizontal, as shown. The center of revolution for the side view is 4¼″ R. and 4″ D.

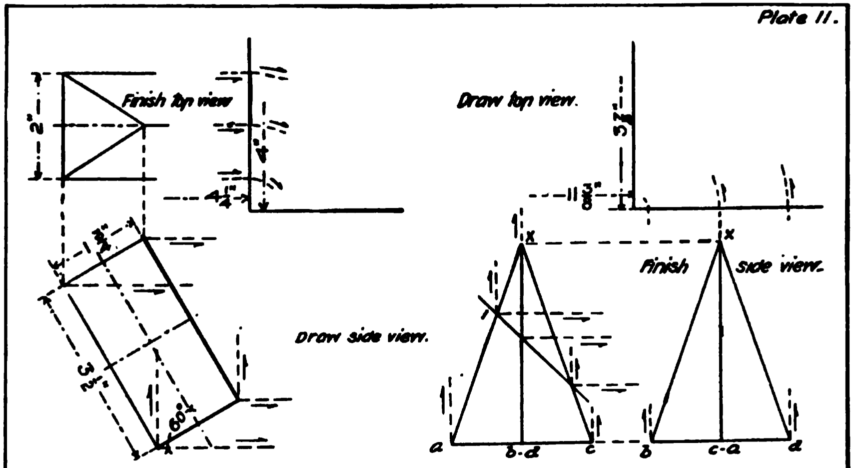


FIG. 64.

Plate 11.

Problem 1.—A right, isosceles, triangular prism in an oblique position.

In all previous problems we have drawn only simple views of the given objects. In this problem we are to work out the views of an object that is tipped—i. e., is in an oblique position.

Begin with the front view. Letter all points in it and also the corresponding points evident in the incomplete top view. The ends of the prism are alike; and, inasmuch as the top view of the upper end is shown directly above the front view of that end, it must follow that the top view of the lower end will be a like figure to this, drawn directly above the front view of the lower end. Then, to find this figure, draw

a vertical line up from each point in the front view of the lower end, and, in the top view, extend each corresponding incomplete lateral edge of the prism to its intersection with the proper vertical line, as determined by the lettering. Connect the points thus found.

Side View.—If now a line from each point in the top view be carried about and down, and a line be carried across from each corresponding point in the front view, the point in which these lines of the same letter intersect will be the point of like letter in the side view. In this way all points may be found. By connecting them, as in the other views, the side view of the prism can be constructed.

Problem 2.—A square pyramid, truncated.

The front and side views of the whole pyramid are given, also the position of the cutting plane in the front view. The problem is, to construct the top view and to show in it, and in the side view, the shape of the surface, called sectional surface, made by truncating the pyramid—i. e., cutting the top from it, as shown.

The diagonal of the base of the pyramid is 2½″ long and its altitude is 3¾″. The pyramid stands corner ways—i. e., with one angle to the front, and so that the two adjacent faces are visible equally. The base, then, in each of these views, will show the full length of the diagonal—namely, 2½″. Also in each of these views, the vertical axis of the view will coincide with the intermediate lateral edge.

Reversing the procedure followed in Prob. 1, in finding the top view, carry lines up and about from the points in the side view to their intersections with lines of the same letters carried up from the front view. Thus the top view can be constructed.

In like manner, the points in which the lateral edges are cut by the oblique plane may be transferred from the front to the top, and to the side views. For example, in the front view, if edge **x-a** is cut in the point 1, the top view of this point must be in the top view of the same edge **x-a**, and directly above its front view; also the side view of point 1 must be in the side view of the edge of **x-a**, and directly across from the front view of the point. And so the other points can be found and the sectional surfaces drawn.

Plate 12.

Problem 1.—A regular, hexagonal tile.

Make a complete working drawing of this object, assuming it to be 27″ long, its width of face 9″ and the thickness of its sides 2″. Scale, 1½″ to 1′.

Location.—The tile is upright. Three faces are visible in the front view, two equally, one each side of the third, the middle face. The axes intersect in the top view, 2¼″ R. and 2⅝″ D. They intersect in the front view 2¼″ R. and 6⅜″ D. The center of revolution for the side view is 4″ R. and 4⅛″ D.

Note that but two faces are visible in the side view.

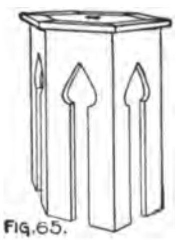


FIG. 65.

Problem 2.—A regular hexagonal tabourette.

Make a working drawing, showing three views, of the tabourette according to the accompanying sketch, Fig. 65, and the following description:

The height under the top is 20″. The width of the faces is 7½″. The top is 1″ thick, and overhangs the faces 1½″. The side openings are 2½″ by 1′ 5″, but may be changed to suit the taste of the pupil. The sides are 1″ thick. The position of the object is the same as that of the tile. Scale, 1½″ to 1′.

Location.—The axes intersect in the top view 12½″ R. and 3⅜″ D. In the front view the base is 8″ D. The center of revolution for the side view is 10⅝″ R. and 4⅞″ D. Swing to the left. Finish the plate in the usual manner.

Note.—The side openings may be made ornate in a simple way and the top may be decorated with some geometric figure, if desired.

SECOND YEAR.

ORTHOGRAPHIC PROJECTION.

Introductory Text.

All those drawings which the pupil made in his first year, representing geometric solids, various articles of furniture, etc., and which we called "working drawings," were, in reality, simple orthographic projections of the objects drawn; orthographic projection being the correct mathematical term for the manner in which they were represented.

Hence, we are not about to take up a wholly new and strange subject, but rather we are to continue our study of a subject which is already somewhat familiar to us, but under another name. We will look at our drawings henceforth, as problems in mathematics instead of merely as pictures, but the process of their making will remain unchanged from that used in the previous year.

All drawings in which are shown the facts of dimension and of arrangement of parts in objects of a structural character, are termed "constructive" or "working drawings." See the paragraphs in "Introductory Text of the First Year," headed "Working Drawings."

The means utilized to obtain the views necessary to show these facts of such an object, is called orthographic, right, or true projection.

The subject is applied descriptive geometry, which treats of the graphical solution of all problems involving three dimensions—i. e., by picturing their relation as determined by reference to certain planes and lines having fixed positions. Its principles are studied abstractly, and problems requiring their practical application are given in order that the pupil may learn, correctly, to make and to read working drawings.

Definition.—Orthographic Projection is a method of representing objects by their images thrown upon two or more intersecting and mutually perpendicular planes, by perpendiculars to these planes from all points of the objects.

Planes.—In accordance with more recent general practice, these planes, called the planes of projection, are assumed as above (the horizontal plane, **H**), before (the vertical plane, **V**), and, where a third plane is helpful, at one side or end of the object (the side-vertical plane, **SV**). The side-vertical plane may be assumed to the left or to the right of the object, as is convenient or the more useful. These three are called the co-ordinate planes of projection. A rectangular glass box, or show case, with the object inside, is often used to illustrate this arrangement of planes, the top of the box representing **H**, the front, **V**; and the side, **SV**; (Fig. 1). Figure 1 also shows how a fourth view of the object may be obtained by the use of an oblique plane of projection.

Views.—The image of the object formed upon **H** is called the top view or plan; that upon **V**, the front view or elevation; while that upon **SV** is called the side view or side elevation. The view upon the oblique plane is called an auxiliary, or helping view.

Lines.—The perpendiculars from the points of the object to the several planes, by the use of which the images are obtained, are called projection lines or projectors. The line of intersection of **H** with **V** and with **SV** is called the horizontal axis of projection (**HA**), while that of **V** with **SV** is called the vertical axis of projection (**VA**). That of the auxiliary plane with **V** is called the auxiliary axis of projection (**AA**).

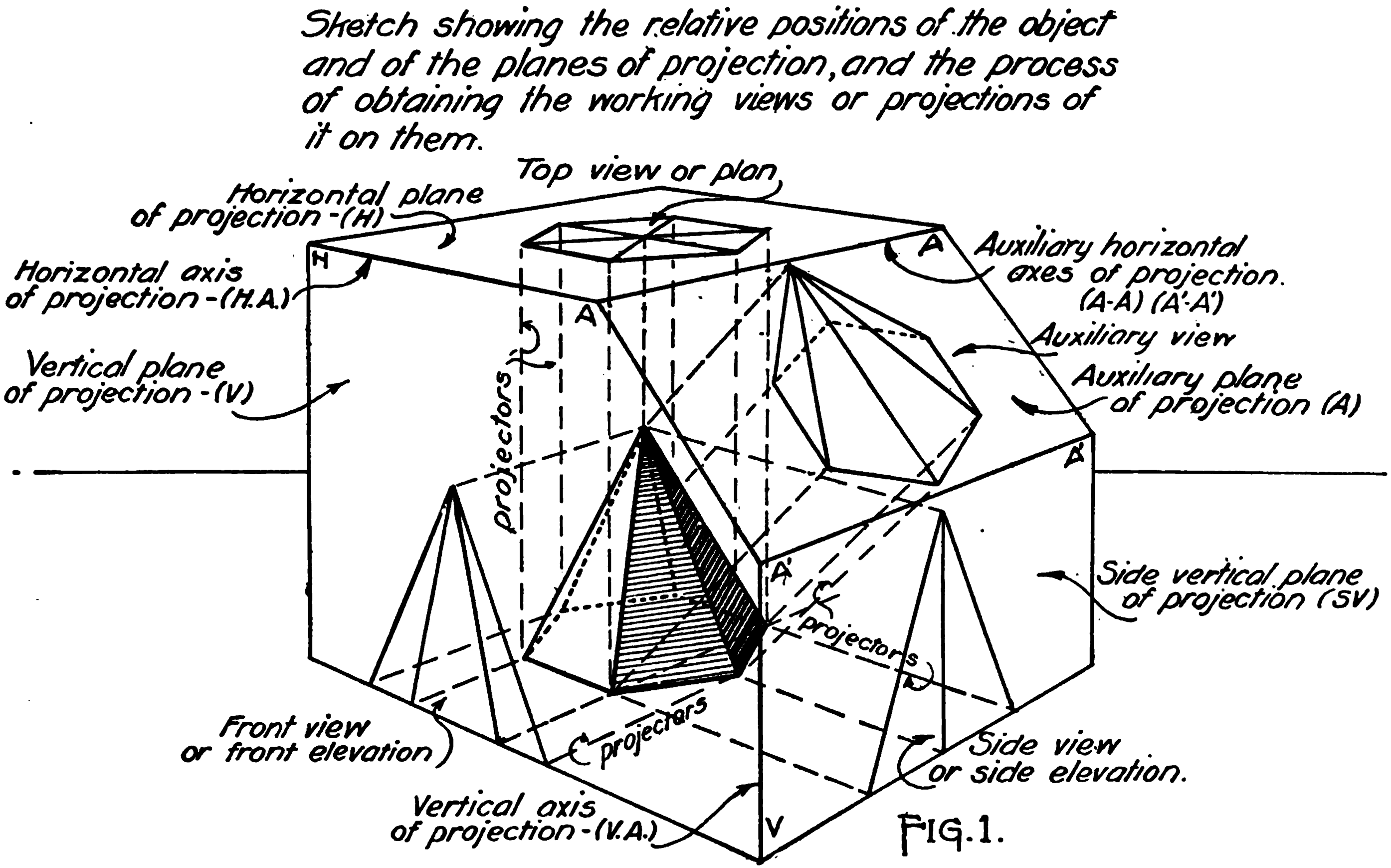

Sketch showing the relative positions of the object and of the planes of projection, and the process of obtaining the working views or projections of it on them.
Top view or plan
Horizontal plane of projection -(H)
Horizontal axis of projection -(H.A.)
Vertical plane of projection -(V)
Auxiliary horizontal axes of projection. (A-A) (A'-A')
Auxiliary view
Auxiliary plane of projection (A)
Side vertical plane of projection (SV)
projectors
projectors
projectors
Front view or front elevation
Side view or side elevation.
Vertical axis of projection -(V.A.)
H
A
A
A'
A'
V

FIG. 1.

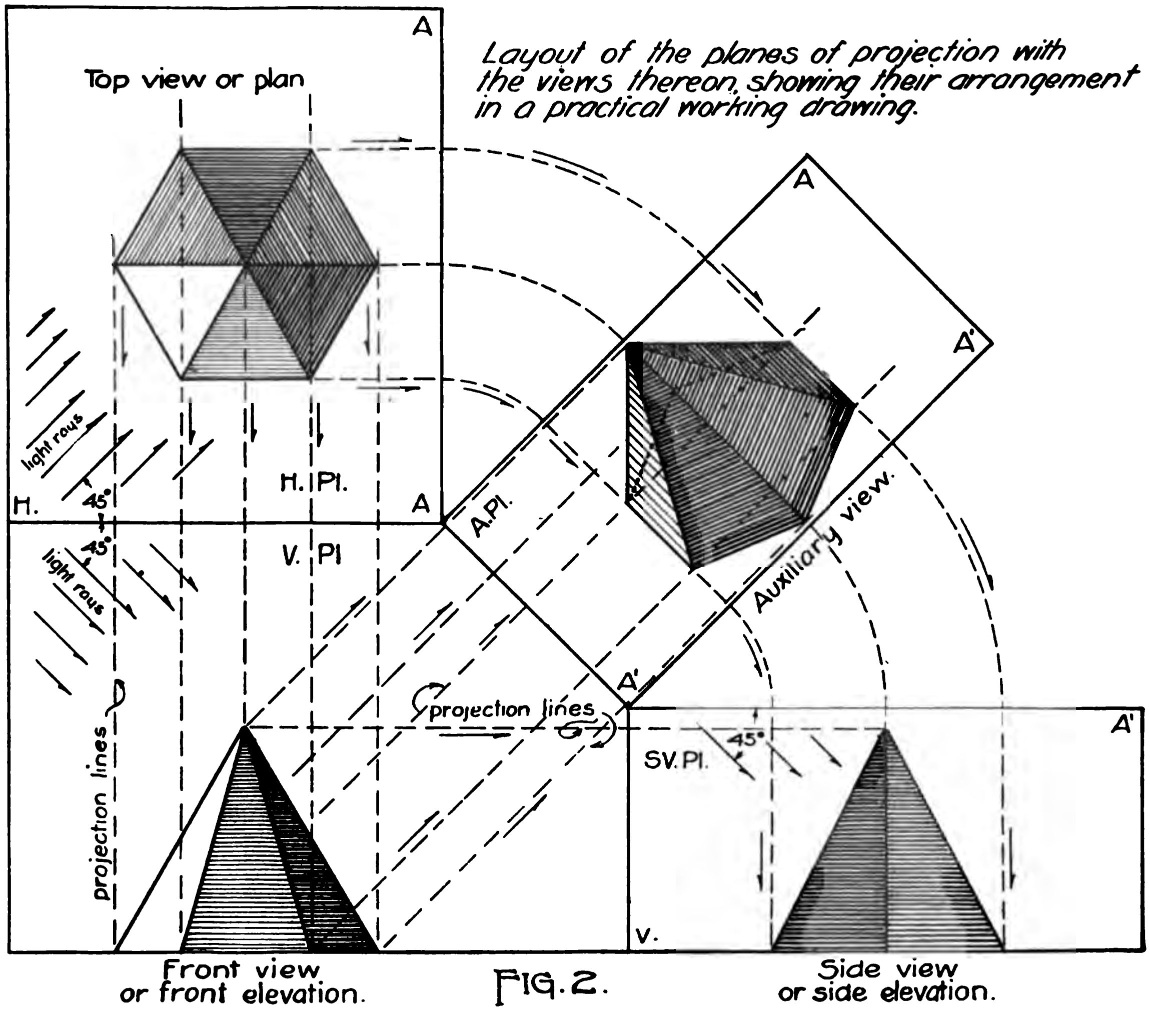

Layout of the planes of projection with the views thereon, showing their arrangement in a practical working drawing.
Top view or plan
A
H. Pl.
H.
A
V. Pl
light rays
45°
45°
light rays
projection lines
A
A'
A.Pl.
Auxiliary view.
A'
projection lines
A'
SV.Pl.
45°
V.
Front view or front elevation.
Side view or side elevation.

FIG. 2.

Layout.—Omitting the oblique plane of projection, imagine the other planes with the views thereon, revolved upon their axes of projection until they lie in the plane of the drawing board, Fig. 2a. Then all above **HA** will be the horizontal plane (**H**); all immediately below **HA** will be the vertical plane (**V**); and all to either side of **V** will be the side-vertical plane (**SV**). Figure 2 shows the layout of the combination of planes shown in Fig. 1.

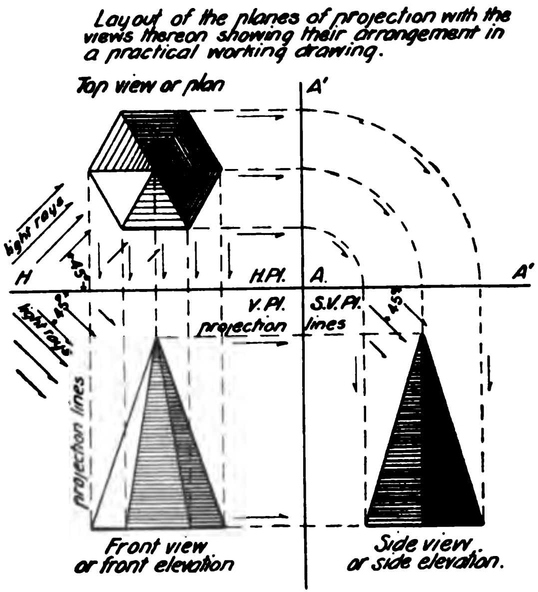


FIG. 2a

Furthermore, in the first instance, Fig. 2a, the front view (on **V**) will be found to lie, point for point, exactly beneath the top view (on **H**), while the side or end view (on **SV**) will be situated exactly to the right or to the left of the front view.

Also, the projectors from like points in any two views will appear as continuous lines perpendicular to the intervening axis of projection.

Reading.—As stated in an earlier paragraph, learning to read working drawings is of equal importance with learning to make them, and to the average man it is even more so. Most business and professional men are called upon to read such drawings, and although themselves not draftsmen, they must know, in general, what drawings of this kind should tell and should understand what, in particular, a given drawing does tell.

This ability the pupil will acquire readily if he will make it a practice to master each problem before going to the next. By this means he will come to a clear understanding of the relation of the various views to each other—i. e., what facts of the object each view shows.

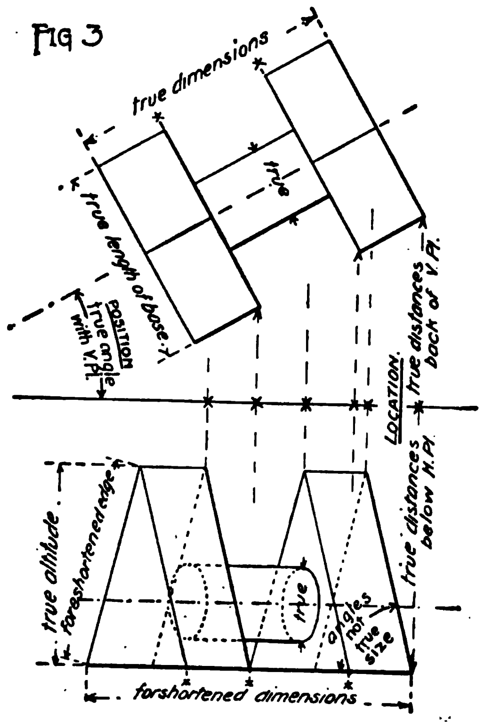
To secure full knowledge of the form, construction, position, location and dimensions of an object from a working drawing of it, it is plain that the information shown in all views of it must be taken together, Fig. 3.

Its form and construction are understood from the general shapes of the various views as they present the different possible appearances of the object.

Its position is determined by noting the true angular relations of its axes, bases, and edges to the axes of projection, **HA** and **VA**.

Its location is established by taking the linear distances of its axes, bases, and edges from the axes of projection.

Fig 3



Its dimensions are learned from those of its axes, edges, and faces which are parallel with some one of the planes of projection. It is only upon such that dimensions may properly be placed.

When the teacher has gone through the introductory text with the class to this point, it will be well for him to take up with them, at the blackboard, various simple exercises in the determining of the positions and locations of points, lines, and planes, etc., illustrative further of the subject of Reading, and also of the following Rules. Thereafter, he should pass to the text explanatory of the subject of Evolutions and start the class on Plate 1.

The remaining paragraphs of the Introductory Text should be referred to as the work advances and occasion requires, as directed at various points in the text of the problems.

Rules of Projection.

1. Any two adjacent projections of a point must always lie in the same projection line.

2. If two points are actually connected, their projections must always be connected.

3. If two or more lines or edges are actually parallel, their projections must always be parallel on any one plane of projection.

4. If two lines or edges intersect, their projections must always intersect in the projections of their point of actual intersection.

5. The projections of a line or edge upon any plane to which it is perpendicular will be a point.

6. The projections of a plane upon any plane to which it is perpendicular will be a line.

7. All positions and locations—i. e., angles and distances—are alike determined from the axes of projection.

8. All vertical distances—i. e., heights—must be shown upon **V** and **SV**. All horizontal distances—i. e., widths and depths—must be shown on **H**. But width (distance from left to right) will be shown also on **V**. And depth (distance from front to back) will be shown on **SV**.

9. In any two views one dimension will be common, the others differing. As width is common to top and front views; depth is common to top and side views; height is common to front and side views.

10. All distances from, and angles with, the axes of projection, shown upon one plane, are distances from and angles with either opposite plane of projection.

11. All movements parallel with one plane of projection will appear in truth upon the planes with which they are parallel. Upon the opposite plane they will be indicated by straight lines parallel with the intervening axis of projection.

12. True lengths of lines and edges, also true sizes of angles and planes, are evident only when they are parallel with a plane of projection, and then only upon that plane with which they are parallel.

13. Points and edges must be "followed up" and located by name, but like points, in all views of an object, must be given the same sign—i. e., either letter or number.

Inking.—All visible edges should be represented by solid lines.

The edges nearest the various planes usually will be visible in the view on the plane to which they are nearest.

All invisible edges should be represented by dotted lines. They should be equal in width to lines used to represent the various visible edges.

The edges farthest from the various planes, usually will be invisible in the view on the plane from which they are farthest.

Edges beneath (usually farthest from **H**, as determined from the front and the side views), will be invisible in the top view.

Rear edges (those farthest from **V**, as determined from the top and side views), usually will be invisible in the front view.

Edges farthest from **SV** (as determined from the top and the front views), usually will be invisible in the side view.

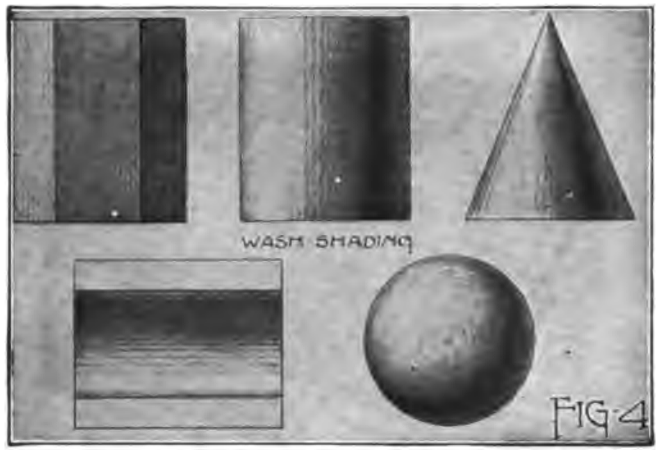
All edges connecting visible and invisible points or two invisible points, are invisible.

All projection lines should be made light, dashed, and in black, and drawn only where a new method or principle is shown.

All construction lines and planes should be made dot-and-dash lines in black.

All axes of projection, when shown, should be made solid, in black.

All axes of form, center lines, and all dimension lines should be made dot-and-dash, in red. All extension lines should be drawn dotted, in red.



Tinting.—Wash shading is a means used to bring out the relative positions of the visible faces of the various objects drawn, as an aid to the complete un-

derstanding of their form. It is the most expeditious and least trying on the eyes of all methods.

The light is usually assumed as coming from above, behind, and from the left of the draftsman, the projections of all rays forming angles of 45 degrees (opening to the right) with the axes of projection in all planes. Then, the surfaces will be light or dark in proportion to the directness or indirectness of the light upon them, Fig. 2.

All plane surfaces, as those of prisms, pyramids, bases of cylinders, etc., are tinted flatly—i. e., uniform in tone throughout. Developments should be tinted flatly and of the same tone as the lightest surface of the original object.

All curved surfaces, as those of the cylinder, cone, and sphere, are graded from the line or point of high light. In such forms allowance should be made for atmospheric reflection, because of which the depth of shade is lessened on that part of the surface diametrically opposite to the high light, Fig. 4.

All views of the same surface in a given position must have the same tone. A change of its position may change its tone.

Washes of stick India ink, of gray or of sepia water color may be used with equally pleasing results.

Working drawings of furniture, apparatus, etc., are not to be tinted, merely shadow lined.

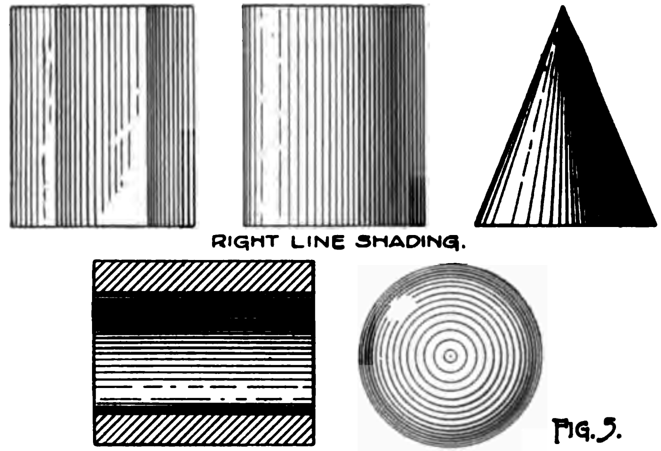


FIG. 5.

Line Shading.—This is a line method of giving different tones to the surfaces of objects. It is especially useful in suggesting the curvature of cylindrical, conical, and spherical surfaces in finely finished drawings intended for illustrative use, such as for catalogs, patent office bulletins, and text books.

The lines are elements of the surfaces shaded. The graduation of tones is secured by varying the spacing and the thickness of the lines. The light is assumed to have the same direction as in wash shading. See Fig. 5.

Evolutions.

Simple views of an object are those in which the axes are severally parallel with the planes of projection.

Oblique views of an object are those in which one or more of the axes are inclined to one or more of the planes of projection. Oblique views are the more pictorial, and frequently aid greatly in the understanding of the form and structural peculiarities of an object. Also, in many combinations and in complex objects, simple and oblique views of different parts occur in the same figure unavoidably.

The purpose of problems in Evolutions or movements of solids, etc., is to familiarize the pupil with the processes of working out such oblique views, for the practical reasons just stated.

Oblique views may be obtained in two ways.

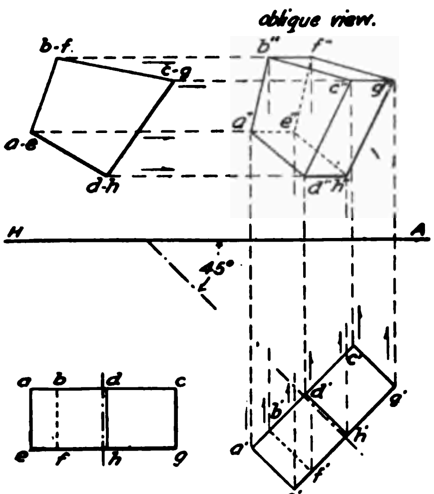


Fig 6

First Method.—Fig. 6. By transposing any simple view, and from it and the opposite untransposed view, deriving the unknown view corresponding to the transposed one, and then continuing this process with the views thus derived. The solution of these problems depends directly upon the application of the truth that all motions made and all distances parallel with any plane of projection can be shown truthfully upon the plane with which they are parallel, Rules 11 and 12. For example: Fig. 6. If the front view be moved to the right or to the left a certain distance, the movement being parallel with **V**, the corresponding top view will be found exactly the same distance to the right or to the left of the previous top view, and, of course, exactly above this new front view, point for point, as established by projection lines from it: In like manner, from a transposed top view, the corresponding front view may be found.

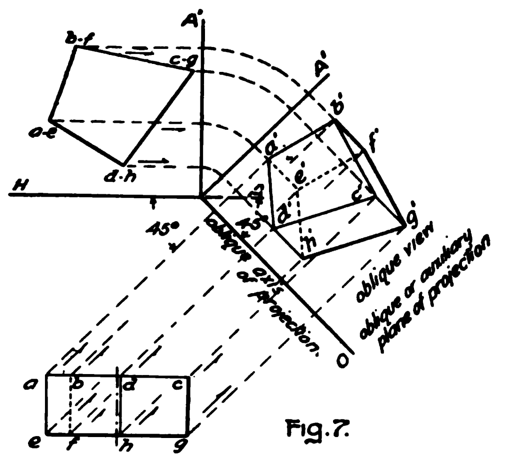


Fig.7.

Second Method.—Fig. 7. By projecting directly from the simple views of an object to an oblique or auxiliary plane. This plane must be perpendicular to one of the planes of projection, usually the vertical, but may be inclined at any angle to the other. Its intersection with **V** and **H** establish the auxiliary axes of projection. The oblique view is then found just as a simple view on **SV** would be obtained. See also Figs. 1 and 2.

Note.—In either case, follow out the method and work out the views: do not try to imagine their appearance.

Evolutions of Lines.—Oblique views of an edge or other line do not show its true length. Simple views do. (Rule 11). If, then, the true length of an oblique edge is wanted, as is often the case, it can be obtained by revolving one of its views until it is parallel with the opposite plane of projection, and deriving the corresponding new view of the edge upon that plane by the method explained above. The process of finding the true length of an edge and of a plane from their oblique views will be explained in detail later where first needed in the solution of a problem.

Size of Plates.—The size of all second, third, and fourth year plates is 12″x17″ inside of the border lines, unless otherwise specified. Upper and lower margins to be 1¼″, and right margin 1½″, when the plate is finished.

Lettering.—All plates in evolutions should have the title, "Evolutions of Solids," and those in sections, "Sections of Solids". If, in either subject, developments appear upon the plate, the words, "and Developments", should be added to the title.

Also, throughout this year, a lettering exercise of fifty words must accompany each plate but the first, just as was the practice of the previous year.

Plate 1.

Problem 1.—Make a diagram illustrating the usual arrangement of the planes of projection and show on these projections of an object in a simple position. Also name all parts of the drawing, as given in Fig. 2a.

Use for this problem the oblique rectangular pyramid the top view of which is shown in Fig. 9, in place of the triangular pyramid used in Prob. 1, Fig. 8. The altitude of the pyramid is 2¾″.

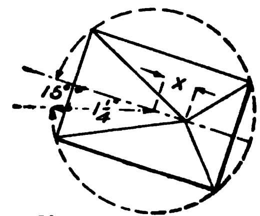


Fig. 9.

Location.—In this and in all the following problems, when used in the specifications, **D,** means down from the upper border line of the plate (or from **HA,** if so noted), and **R** means to the right from the left border line, excepting when it refers to the opening of an angle.

Also, unless otherwise stated, all angles made by the axes of the objects, as these are given in the specifications, are angles with the planes of projection. Thus, 60 degrees L. to H, or 45 degrees R. to V, means, in the first instance, that the axis forms an

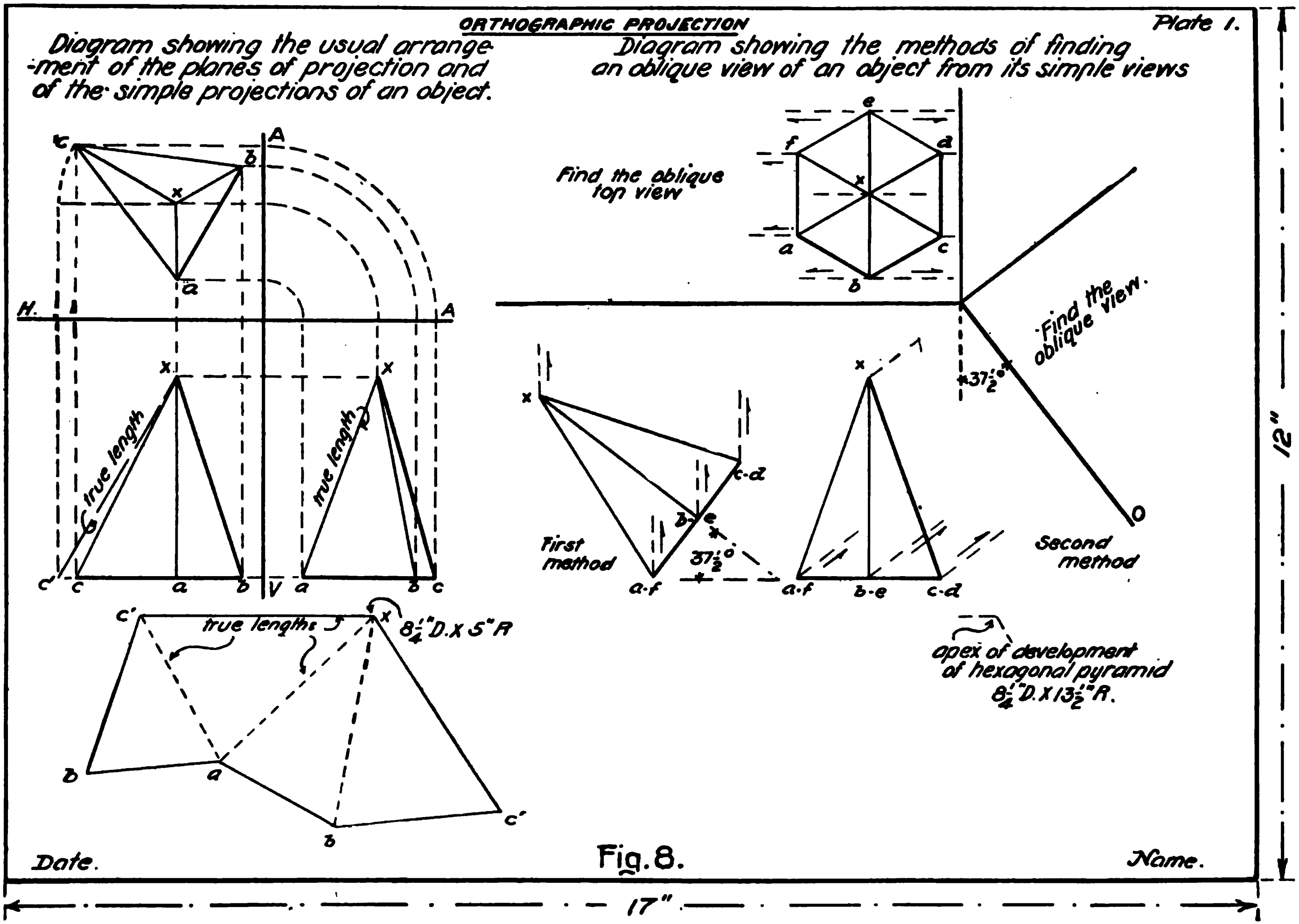

ORTHOGRAPHIC PROJECTION
Plate I.
Diagram showing the usual arrange-ment of the planes of projection and of the simple projections of an object.
Diagram showing the methods of finding an oblique view of an object from its simple views
Find the oblique top view
Find the oblique view.
true length
true length
true lengths
$8\frac{1}{4}$"D.X 5" R
First method
Second method
$37\frac{1}{2}°$
apex of development of hexagonal pyramid $8\frac{1}{4}$"D.X $13\frac{1}{2}$"R.
Date.
Name.
17"
12"

Fig. 8.

angle of 60 degrees with the horizontal plane and opens to the left, while in the second, the axis is at an angle of 45 degrees with the vertical plane, opening to the right, in each case determined from **HA**. See Rules 7, 10, and 11.

Place the horizontal axis of projection (**HA**) 4¼″ D. and the vertical axis of projection (**VA**) 3½″ R.

In the top view, the center of the circle circumscribing the base of the pyramid, is 2⅜″ D. and 2″ R. In the front view, the base of the pyramid is 7¾″ D.

For the development, if not apparent (Rule 12), the true lengths of the lateral edges (those from the vertex to the base) must be found. This is merely a problem in the evolutions of lines, as mentioned in the preceding paragraphs.

In Fig. 8, Prob. 1, notice that the edge **x-a** is parallel with **SV**, and that its true length is evident on **SV**. This is also the true length of edge **x-b**, the pyramid being isosceles.

Now, if the other edge, **x-c**, be revolved, in the top view, as indicated, about point **x** as a center, until it is parallel with **HA**, hence with **V**, and its lower end in its new position, **c′**, be connected with point *x*, which is stationary, this line, **x-c′**, will be the true length of the edge **x-c**. By a like process, the true length of any oblique edges can be found upon any of the planes.

The development of the pyramid is then laid out by the triangulation method of reconstructing a polygon given in Prob. 1-3, Pl. 2, First Year, the edges of the pyramid being the sides of the triangles.

Problem 2.—Make a diagram illustrating the methods of finding an oblique view of an object from its simple views.

Draw what is given as the statement of Prob. 2, Fig. 8, and work out the oblique top view and the oblique side view called for. Name all parts of the drawing, when completed, as shown in Fig. 7.

Notice in Fig. 6 and Fig. 7 that the oblique views found by the two different methods are identical. This is simply because, in both drawings, the planes of projection upon which the oblique views were thrown, have exactly the same inclination to the axes of the objects.

It follows, then, in this problem, that if the axis of the pyramid in the transposed position, first method, is inclined at an angle of 37½ degrees to the horizontal plane, the oblique or auxiliary plane, second method, must be inclined at 37½ degrees to the axis of the pyramid in its given position, in order that the two oblique views shall be identical, as is wished.

Location.—Place **HA** 4″ D. and the point of intersection of the axes of projection 13″R. Each side of the base of the regular hexagonal pyramid is 1¼″ long, and the altitude of the object is 2¾″. In the top view, the center of the base is 2½″ D. and 11¾″ R. In the front **view the base is** 3¾″D. **from HA.** Two sides of the base are perpendicular to **V**.

Draw the simple front and top views, first. Then draw the transposed front view, first method, and from it and the simple top view work out the oblique top view. Next, work out the oblique side view, second method. Finally, lay out the development, in the space below, with the vertex where indicated. The true length of a lateral edge must be found for this, but as the pyramid is regular, one is sufficient for all. Ink, print in full, as directed, clean up and then tint as explained in the paragraphs on tinting.

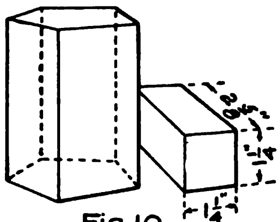


Fig. 10

Plate 2.—Evolutions of Solids.

Read the whole problem through carefully, first. Then draw the complete statement of the problem before attempting its solution. To start the problems right, make it a practice always to do this.

Given a right, regular, pentagonal prism; its base inscribed in a circle of 1¼″ radius; its axis vertical; its height 3″; its right face perpendicular to **V** and to H.

To the right of this lies a right, square, horizontal prism of the size and in the position shown in Fig. 10, its faces parallel in pairs with the planes of projection. Draw **HA** 6⅛″ D.

(1) For the top view of the pentagonal prism, place the center of the circumscribing circle 2⅛″ R. and 2¾″ above **HA**. Draw the view; a regular pentagon, with its right side perpendicular to **HA.**

Place the point of intersection of the axes of height and of width in the front view of this prism 2⅛″ R. and 2¾″ below **HA**. Draw the view.

Place the point of intersection of the axes of the horizontal prism, in the top view, 4⅝″ R. and 2¾″ above **HA**. Draw the top view; a rectangle, 2⅝″ by 1¼″, having its shorter side parallel with **HA**. In the front view, the axes, intersect 4⅝″ R. and 3⅝″ below **HA**. This view will be a square 1¼″ on each side. Letter all points in both views of both objects.

(2) Redraw the front view of the horizontal prism with its axes intersecting 9⅞″ R. and at the same level as in (1).

Redraw or transpose the front view of the pentagonal prism with its right lower edges 8⅜″ R. and 4¼″ below **HA,** the object so tipped that its right face rests against the upper left edge of the horizontal prism. Letter completely, just as lettered before.

To find the top view corresponding to this transposed front view, use the first method of deriving oblique views, already explained, Fig. 6.

Inasmuch as the movement of the objects has been directly to the right, parallel with **V**, on **H**, indicate this motion by lines parallel with **HA**, drawn to the right from all points of the top view of (1), (Rule 11). Then draw a projection line up from each point in the front view of (2), to its intersection with the line of like letter from (1). By this means all points may be located in their new positions. Then, by connecting them properly, i. e., as they are actually connected (Rule 2), this view may be completed.

(3) Transpose the whole top view just drawn (2), so that its right and left axis intersects **HA** 11¾″ R. at an angle of 52½ degrees R. with **HA**. Place the left angle of the lower base of the pentagonal prism in this axis 1⅝″ from **HA**, measured on the axis. In transposing views of this kind, use the coordinate method of transferring polygons, Probs. 5 and 6, Pl. 2, First Year. Letter all points, as in previous views.

Now, inasmuch as this last movement of the objects has been directly to the right without change of level, hence parallel with **H**, on **V**, show this motion by lines parallel with **HA** drawn to the right from all points of the front view of (2). (Rule 11). Then

draw a projection line down from each point in the top view of (3) to its intersection with the line of the same letter (2). By connecting the points thus found, as in the previous views, this view can be completed.

Before inking the figures, their accuracy should be tested in accordance with Rule 3. The projections of all edges which, by construction or arrangement, are parallel, must always be parallel.

In inking, show all projection or construction lines, axes, and invisible edges. Omit the letters placed on the figures, but print the title, then tint.

The teacher may substitute a regular heptagonal prism for this problem at his discretion.

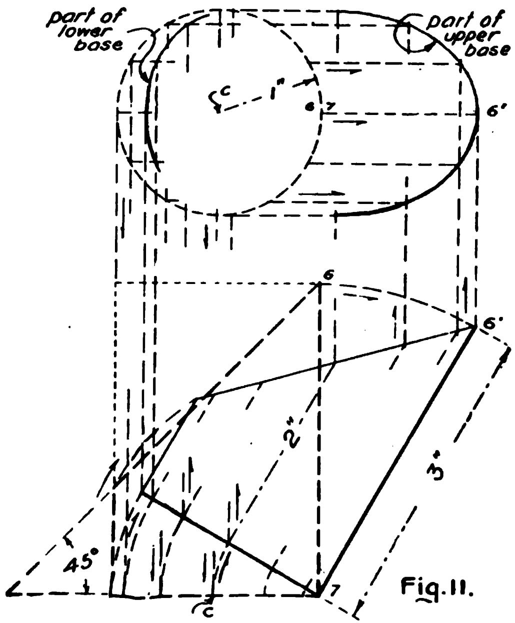


Fig. 11.

Plate 3.—Evolutions of Solids.

Problem 1.—Read through and state the problem first.

Given a right, circular cylinder; diameter 2″; altitude 3″; axis cut 2″ above the base by a plane inclined at 45 degrees R to the base. Draw **HA** 4¼″ D.

(1) The cylinder is to be drawn so tipped that its axis is inclined 60 degrees left to **H** but parallel with V. First draw the top and the front view of the object, assuming it to be vertical, and then tip it, as shown in Fig. 11.

In the temporary front view, point **C**, the center **of the base, is 1¾″ R. and 3¼″ D. from HA, and in** the top view, 1¾″ R. and 2⅛″ D. Divide the top view, a circle, into twelve equal parts, and project these points to the base in the front view, numbering them.

Now, in the front view, tip the cylinder, on point 7, to the required angle, carrying the points just found, to this new front view.

The top view corresponding to the tipped front view is found by the First Method of obtaining oblique views (Fig. 6), and is identical with (2) of the previous plate excepting, in this case, that the points establishing the outline of the bases are connected by freehand curves, forming ellipses, instead of by straight lines, forming angular polygons.

(2) Transpose the top view just drawn so that its axis makes an apparent angle of 45 degrees R. to **V**. and that point **C** is 6¼″ R. and 1½″ back of **V**. Use the coordinate method for transferring. Number all points in the outlines of the bases, as before. Work out the corresponding view. See Pl. 2, (3).

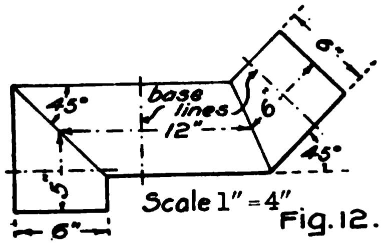


Fig. 12.

Problem 2.—Cylindrical pipe.

Given the front view of a 6″ cylindrical pipe composed of three sections, having the dimensions and arrangement shown, Fig. 12.

(1) Draw the front view with the lower opening centered 11½″ R. and 3½″ below **HA**. Draw the axes of the sections first.

(2) To work out the top view, draw the circle which is the projection of the vertical section on **H**, and divide this into twelve equal parts. From these points carry elements (See "Definitions" page 24) the whole length of the pipe. Then the top view of the oblique ends of the second and third sections will be found in the same way in which the ellipses representing the bases were obtained in the previous problem.

(3) Lay out the developments of the sections in order, the lowest to the left of the plate, centered both ways, on a base line 2¼″ above the lower border line and with the axis of each section vertical. It is well to draw the development of the middle section first in the center of the space, and then to place the development of an end on each side.

Suggestion.—Note, that in the front view, as the axis of the pipe is parallel with **V**, the true lengths of the several sections are shown. Hence, in this view all elements must be evident in their true lengths, for they are parallel with the axis of length in each section, and therefore are parallel with **V**. Use them in laying out the developments, spacing them properly, (a twelfth of a circumference apart), and with their extremities correctly located in reference to the base line, as determined by the right sections made through the sections where shown. This is an application of the coordinate method of transferring polygons. See Prob. 5-6, Pl. 2, First Year.

Developments.—The practical value of these is too often unknown and unthought of by the pupil. All manner of sheet metal working of tinsmithing, and of paper box making begins with the laying out of the developments of the things to be made. The products of the first include hoods, flues, chimney tops, grain chutes, bay coverings, gutters and down spouts, cornices and architectural ornament in sheet iron and in copper. Work of the second are articles of utility, coal hods, dust pans, scoops, funnels, pans, tea-kettles, and all varieties of tinware; and the third covers every conceivable shape of box made from card board. These are but a few of the practical uses of developments. Lastly, the making of developments is one of the best exercises for increasing the pupil's ability to read working drawings.

In inking this plate omit all projection and construction lines excepting those used to obtain the oblique position of the cylinder in the first problem. Before tinting, practice, using Fig. 5 as an example.

Plate 4.—Furniture Drawing.

Some piece of furniture such as a laboratory table for chemistry, physics, biology, etc., a drawing table, bookkeeping desk, or teachers desk, or a case or cup-

board, should be selected or assigned which is similar to that shown in Fig. 13.

The pupil must make a preliminary free hand constructive sketch of the model chosen, inserting all necessary dimensions, and then make his working drawing from the sketch, laying it out to such scale as will best suit the size of the plate.

This working drawing should show all the general facts, important details of construction, and all dimensions needed for the making of the object. Also specifications as to the kind of materials to be used and the nature of the finish may be stated. Shadow line; do not tint the drawing.

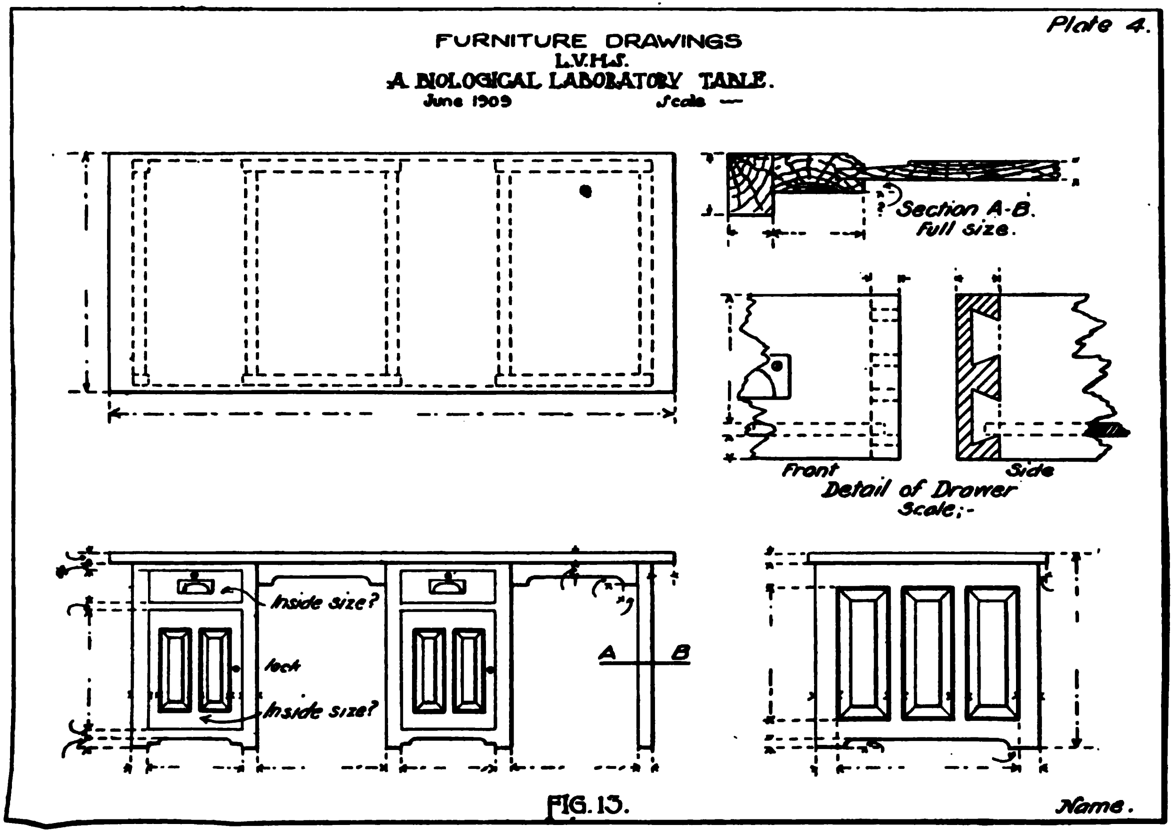


FIG. 13.

Sections.

The views of the exterior of an object seldom make clear its internal structure, or its concealed arrangement and operation of parts. In such a case it is customary to remove some portion of it. This is done by passing an imaginary cutting plane through it in such a way as will be most helpful, and then representing what is thus exposed. Such drawings are called sectional views or simply sections. Fig. 14, is a partial section of a common faucet; note the interior mechanism, of which no outside view could give any idea.

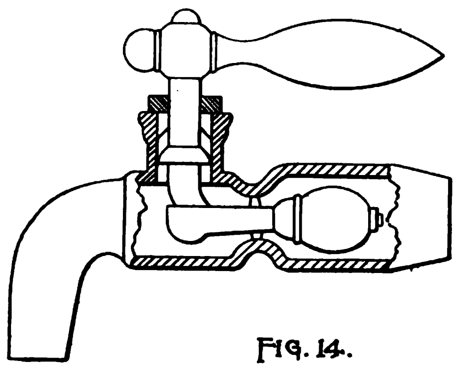


FIG. 14.

Also, in irregular and oblique forms, sections give directly, truths of dimension, angles, etc., not otherwise evident nor more readily found, and the use of cutting planes simplifies the solution of both abstract and applied problems in penetrations, all of which will be shown later.

Sectional views are very common, as illustrations, in all technical and scientific books, and they are invaluable in all structural work.

Such cuttings are usually made either parallel or coinciding with the long axis or length of the object, or perpendicular, or oblique thereto, being then called respectively, longitudinal sections, cross or right sections, and oblique sections.

Also, in structures the principal axes of which have fixed positions as in machinery, vessels, buildings, etc., vertical and horizontal sectional views are an absolute necessity to their construction. For example, in the case of a building, these latter, the horizontal sectional views, taken at different levels, are the several floor plans, without which the structure could not be erected.

In finding the true sizes of the sectional surfaces in the following problems, use the second method of determining oblique views, namely, by the use of oblique or auxiliary planes parallel with the cutting planes.

Definitions.

Traces.—The point in which a line penetrates a plane is the trace of that line in that plane.

The line in which a plane intersects another plane is the trace of the first plane in the second.

Plate 5.

Problem 1.—(1) Given an irregular, oblique, triangular pyramid; base horizontal; angles of base in the circumference of a circle of 1⅜″ radius; altitude 3″.

In the plan (top view), the vertex is 2″ R. and 1⅞″ D. It must not coincide with the center of the circumscribing circle. In the front elevation (the front view), the base is 8″ D. Draw the plan first, then the front and side elevations. One lateral edge, **b-1**, Fig. 15, is parallel with **V**. The plan and the

front elevation of another, **b-3**, are perpendicular to **HA.** The third edge, **b-2**, must be oblique to all planes. Letter all points.

(2) Pass a plane perpendicular to **V**, and inclined 45 degrees R. to H, cutting the axis, **b-c**, $1\frac{1}{4}''$ above the base. Point **c**, the center of the base, is the point of interseetion of the bisector of its angles. (See the definition of "the axis of a pyramid"; also see Prob. 2, Pl. 3, First Year).

The sectional or cutting plane, being perpendicular to **V.**, its projection thereon (its front view) will be a line (Rule 6) inclined downwards to the right at an angle of 45 degrees to **HA.**

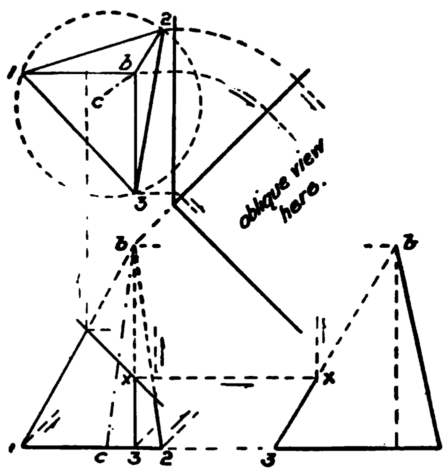


Fig. 15.

(3) To find, in the plan, the resulting sectional surface, or the traces of the plane in the faces of the pyramid, project from the points in which the lateral edges are cut in the front elevation, to the plan of the corresponding edges. In a similar manner, carry these points to the edges in the side view. See Prob. 2, Pl. 10, First Year.

But point **x**, in the front elevation of the edge **b-3**, cannot be transferred to the plan of **b-3** in this way, because the edge and the vertical projection line from it coincide. If, however, the point **x**, carried from the front view to the side view of **b-3**, be then projected up, it can be revolved to its proper place in the top view of this edge without difficulty.

(4) Now, by connecting the points found in the plan and in the side elevation, these views of the sectional surface can be drawn.

(5) Find the projection of the frustum (see definitions, first year text) of the pyramid upon an oblique or auxiliary plane assumed to the right of and parallel with the sectional surface. This is to be done by the "second method" of obtaining oblique views, as fully explained and illustrated in the paragraphs on 'Evolutions", Fig. 7, and in connection with Prob. 2, Pl. 1, Fig. 8. The problem referred to is almost identical with this one.

Locate the center of revolution and the auxiliary axes of projection where they will not conflict with the views already drawn. Then work out the oblique view of the whole pyramid. After which, carry the points of the sectional surface from the front view to their proper edges in the oblique view, and connect them. This view of the sectional surface will show its true size. Why?

(6) Develop the whole pyramid, locate the sectional line, or trace of the cutting plane therein, and

attach the sectional surface and the base. This development is to be drawn in the space below the problem, the placing being left to the pupil to determine.

For its development, the true length of every edge in the object must be known; Rule 12. The sides of the base are in true length in the top view. The true length of the lateral edge **a-1** appears on **V**, and that of edge **b-3**, on **SV**. The true length of edge **b-2** alone must be found. Revolve or transpose this edge to a position parallel with **V**, using the vertex in the top view as the center, and establish the corresponding front view on **V**, just as has been explained in the text accompanying Plate 1.

To determine the correct position of the section points, note or find their positions on the true lengths of the edges, and transfer these distances to the edges of the same letters in the development. When these points are connected in the development, the resulting sectional lines should equal the lines of the same lettering in the auxiliary view of the sectional surface. Check the work in this way before inking. Attach the sectional surface and the base.

In inking, in all views and in development, dot that portion of the pyramid which has been removed, as well as the invisible edges of the frustum.

Note.—Any other form of pyramid may be substituted for this, at the discretion of the teacher.

Problem 2.—Given a right, circular cylinder; diameter 2½″; altitude 3″; axis, vertical. The axis, in the plan is 11⅞″ R., and 2⅜″ D. The lower base, in the elevation, is 8″ D.

In the front elevation, a plane perpendicular to **V** and inclined 60 degrees **L.** to **H**, cuts the right element 5/16″ from the top. Also, on the same side, another plane, perpendicular to **V**, and inclined 30 degrees **R.** to **H.**, is passed, cutting the right element 5/16″ from the bottom.

(1) Draw the plan, the front, and the side elevation. To begin with, divide the circumference of the circle representing the plan into twelve equal parts, and project lines from these points through the front and side elevations, these lines being elements of the cylindrical surface. See, Definitions; First Year.

(2) Find the sectional surfaces in the side elevation, these not being apparent in the ther views. To do this, carry, from the front elevation, the points in which the elements are cut by the sectional planes, in this view, to the elements of the same letters in the side view, and then connect them. The outlines will be elliptical curves, to be drawn freehand.

(3) Show the true size of these "sections" upon auxiliary planes to the left and to the right of the front elevation. Refer to the previous explanations for information, if needed.

(4) Develop the cylinder, and locate thereon the traces of the cutting planes. See Prob. 1, Pl. 8, First Year, and also Pl. 3, Second Year.

Draw as many of the twelve elements in the development as were cut by the planes, and transfer to them, from the elements of the same letters in the front and side elevatoins, their section points.

Note.—A cone may be substituted for the cylinder, if desired.

Plate 6.

Sections and Evolutions of Solids, with Development.

Problem 1.—Given a cube having an edge of 1⅝″, one diagonal of the top of which is perpendicular to and the other parallel with **V.**

Pass a plane perpendicular to **V** through all the faces, cutting each face in a line parallel with one diagonal and midway between this diagonal and a corner of the face. As shown in Fig. 16, in the front view, the trace of this plane passes from the center of the upper edge of the right face downwards to the center of the lower edge of the left face, intersecting the intermediate vertical edge at its center. The section will be a regular hexagon, although not apparent as such in any of the following views.

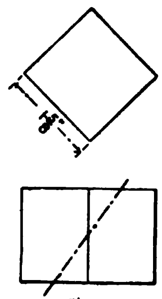


Fig. 16

The pupil must determine the proper spacing for all views and developments on this plate, using one-half the plate for each problem. As stated in the first year text, it is not well for him to become dependent upon "full specifications" for "laying out" his work, nor upon "full explanations of solution." Hence, whenever particulars of this kind are lacking, he is expected to rely upon his own knowledge and judgment as to "what to do", and "how to do it". In this way alone will he come to a working command of the subject. Explanations will be given when a new method or a new principle is involved in the solution of a problem. These the pupil must learn and must remember together with those already given.

(1) Draw the top and front views of the cube, and letter all corners in each. Then, in the front view, pass the plane as described above, number all points in which it cuts the edges, and show the section in the top view.

(2) Tip the front view so that the vertical axis is inclined 60 degrees **L.** to **H**, and find the corresponding top view, which, of course, will be directly above the new front view and horizontally directly to the right of the first top view.

(3) Turn the top view just found so that its right and left axis is inclined 60 degrees R. to **HA**, and work out the corresponding front view. If any explanations are desired, refer to those accompanying Pl. 2.

(4) Develop the object in the space below the problem. The true lengths of all edges are shown. Develop the whole cube first, then locate the section line and attach the sectional surface and the bases.

Problem 2.—Given a regular hexagonal pyramid; side of base, 1¼″; two sides of the base perpendicular to **V**; altitude 3″; axis of pyramid parallel with **V**, and inclined 60 degrees **L.** to **H.** A plane parallel with **SV** cuts the axis 1¼″ above the base.

(1) To construct the front view in the inclined position specified, the top and the front views of the object placed vertically might be drawn and then tipped, as in Prob. 1, Pl. 3, but a more direct way is preferable.

Draw the axis at the required angle. Through its lower end (c) draw a perpendicular. At point **c**, Fig. 17, draw an arc somewhat greater than a semicircum-

ference, using a radius of 1¼″, the side of the base of the pyramid. As but two lateral faces of the pyramid will show in the front view, from point **3** on the arc, (opposite **c**), with the radius just used step off **3-2**, **2-1**, and **3-4**, **4-5**. Connect these; the figure will be an auxiliary view of one-half of the base upon a plane

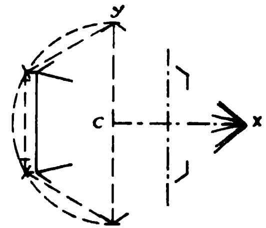
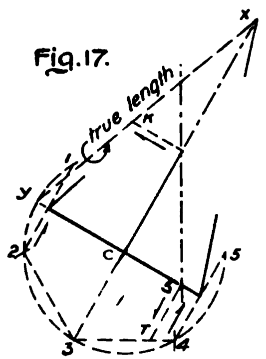


Fig. 17.



parallel with the base in its required position; hence its true size. From it the width of the base is measured in the front view. By a like process to that used to obtain the plan in Prob. 1, Pl. 3, in combination with the front view, the top view is found as shown in the figure. Construct the views, and letter all points in them. Then, from these two views, obtain the side view, lettering its points also.

(2) Now, pass the cutting plane. As this is parallel with **SV**, hence perpendicular to both **V** and **H**, its plan and front elevation will be a line; Rule 6. The true shape and the true size of the section will show in the side elevation; Rule 12.

(3) Develop the frustum; first, however, developing the entire pyramid. The true length of a lateral edge is nowhere shown. This can be found by revolution, as previously done, or by construction. The latter method is the more serviceable, as later use will demonstrate.

In the front view, **x-c**, coinciding with the axis, is the true length of the altitude. In the top view, **c-y**, a semi-diagonal, is the true distance from the foot of the axis to all the angles of the base, and the angle **x-c-y** is a right angle. These constitute two sides of a right triangle, the third side of which, the hypotenuse, is the lateral edge, **x-y**. Therefore if they are combined, as shown in the front view, and their extremities are connected, the connecting line will be the true length of all the lateral edges, this being a regular pyramid. Use it in laying out the development, as shown in Plate 1, Prob. 2.

To this measuring line, **x-y**, the section points can be carried, as point **k**, and their true positions in the several edges thus can be determined. Then, transfer them to the edges of the same letter in the development.

The points in which this sectional plane cuts the sides of the base of the pyramid, are located by drawing this section line, **s-t**, in the auxiliary of the base from which the front view was obtained.

Attach the sectional surface and the base. Check the section lines in the development with the sides of the section shown in the side view, before inking. They should agree exactly.

Plate 7.—Sections.—Practical Problems.

The pupils knowledge of the subjects of Evolutions and of Sections will have little value until it is turned to practical use in the solution of problems such as the draftsman meets daily.

Figures 18 to 26, inclusive, are dimensioned sketches representing various common objects in the world of mechanics. The pupil is to be assigned the problem of making, on this plate, working drawings of at least two of them, as particularly described below.

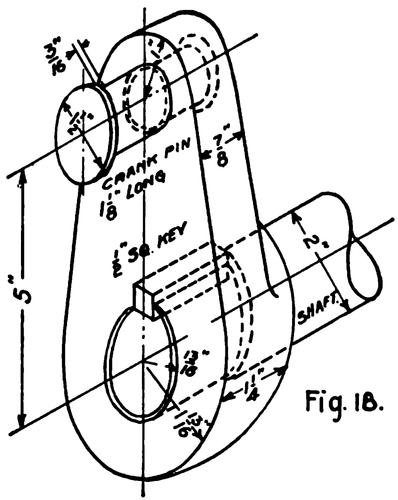


Fig. 18.

Figure 18. An engine crank. Draw the front view, the top view, and a vertical section, as a side view the cutting plane to coincide with the axes of the crank pin and of the crank shaft. Draw full size. In inking, shadow line the drawing and "hatch" or "section line" the section made through the crank, but not that through the pin or shaft. Figures 22 and 23 are sectioned lined to indicate brass; Fig. 20 for cast iron. Steel is shown by alternate narrow and wide spacing of the section lines. The crank is of steel.

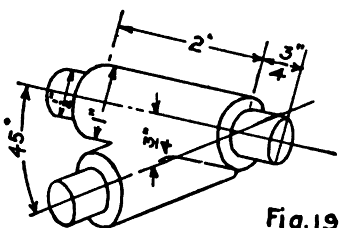


Fig. 19.

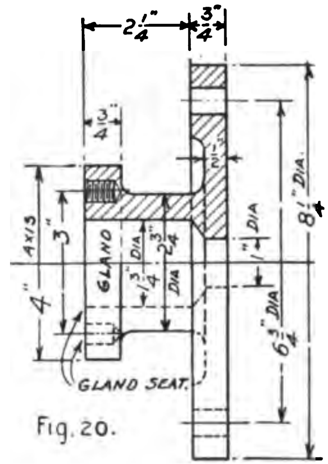


Fig. 20.

Figure 19. Skew pins. Make three views of the skew pins shown in Fig. 19. Scale, full size. Axes of pins are horizontal and inclined to **H** so that the bisector of the angle between them is at 30 degrees **L** to **V**.

Figure 20. Cylinder head. Given the side view, part in section and part full, from which to draw the front and the top views complete, and a side view in

section. The head is fastened to the cylinder by six ½″ stud bolts uniformly spaced. The gland cover and seat for it are approximate ellipses having a 4″ major and a 2¾″ minor axis. Two ⅜″ stud bolts hold it in place. Indicate the screw threads in the manner shown. Scale, ¾ full size.

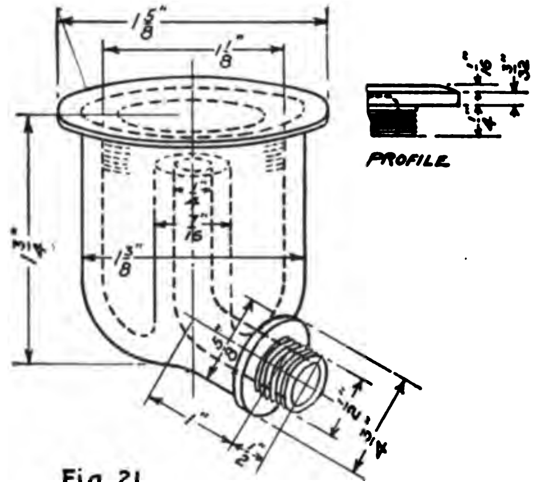


Fig. 21.

Figure 21. Oil cup for an engine. Draw the top view with the cover removed and the stem to the right. Draw the side view in full, and as the front view, a vertical section coinciding with the axis and parallel with V. Draw the cover separately. The threads of the cover are 16 per inch and of the stem, 13 per inch. Indicate and mark them but do not try to draw them. The "profile" shows the shape of the cover in section at its edge. Scale, double size.

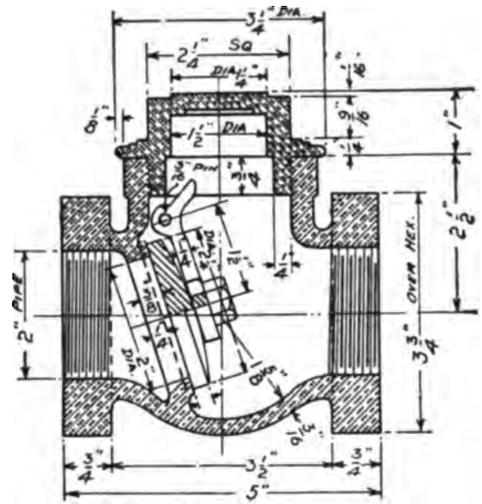


Fig. 22.

Figure 22. A flap valve. Given the longitudinal section of a flap valve, to draw the front, top and side views entire. Also draw three views of each part separately, the cap, the valve seat cover, and the lever. The valve operates as follows. The water flows from left to right and raises the valve cover. When the supply is cut off the cover drops of its own weight, thus preventing the water from flowing back.

Valve proper. Each end of the valve is a regular hexagon. Thus a wrench can be applied and the valve screwed to a pipe. The section is taken through the long diagonal of the hexagonal end. The valve is divided into two compartments by a diaphragm in which is a 2″ hole. The threaded ends should have an inside diameter of 2⅜″, this being the outside diameter of a 2″ pipe. It has 11½ threads per inch.

Notice that the valve seat has a raised boss slightly larger than the valve cover. This boss is ground to insure a close fit of the cover.

Valve seat cover. This is circular, 2¼″ in diameter, flat on the lower side and convex on the upper. The small projection in the center is ⅜″ in diameter and has 16 threads per inch. This projection passes through the valve lever and is secured to it by a hexagonal nut having a long diagonal of 13/16″, and a height of ⅜″.

Valve lever. This is ½″ wide, has an enlarged circular end, 1″ in diameter, and is held in place by a 3/16″ pin.

Valve cap. This is square on top. The circular part is 2¼″ in diameter and has 16 threads per inch. The inside of the cap it cored out to reduce its weight. Scale, full size.

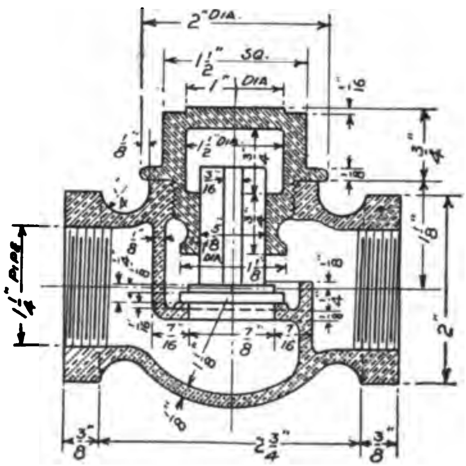


Fig 23.

Figure 23. A check valve. Make three views of the assembled valve and also three views of each part. Its operation is similar to that of the flap valve. The

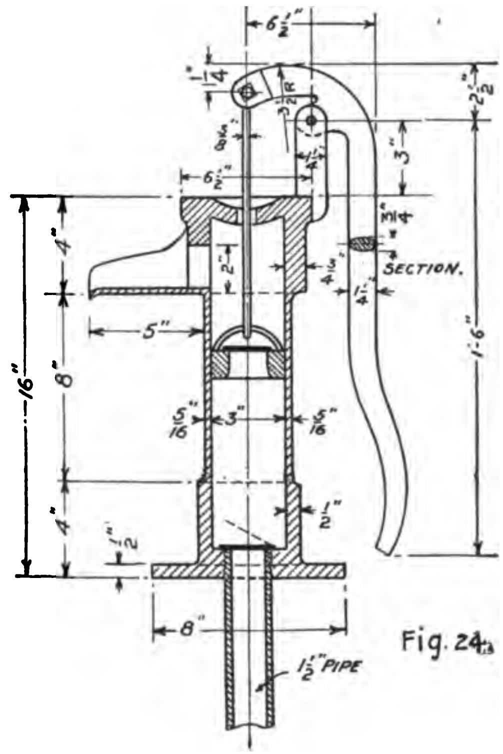


Fig. 24.

water flows from left to right and raises the valve plunger. When the flow ceases the plunger drops and prevents the return of the water.

The valve consists of three parts, the body of the valve, the cap, and the valve plunger. The inside diameter of the ends should be 1⅝″, as that is the outside diameter of a 1¼″ pipe. The number of threads at the ends is 11½ per inch. The longitudinal section shown is taken through the long diagonal of the hexagonal end. A cross section of the valve plunger above the valve disc is a cross. Scale, full size.

Figure 24. A lift pump. Draw three views of the pump including the section shown. Also draw three views of the valve and rod, and of the handle. The inside width of the spout is 2″. Scale, 2″ to 12″.

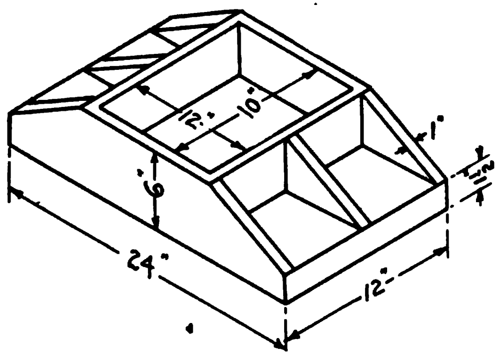


Fig. 25.

Figure 25. A cast iron base for a post. Draw three views of this object, the longer dimension to be parallel with V. Scale, 1½″ to 12″.

Figure 26. A cast iron cap for a post. Draw three views of this object with a vertical section through the center, perpendicular to **V**, as the side view. Draw with the longer dimension parallel with **V**. Scale, 1½″ to 12″.

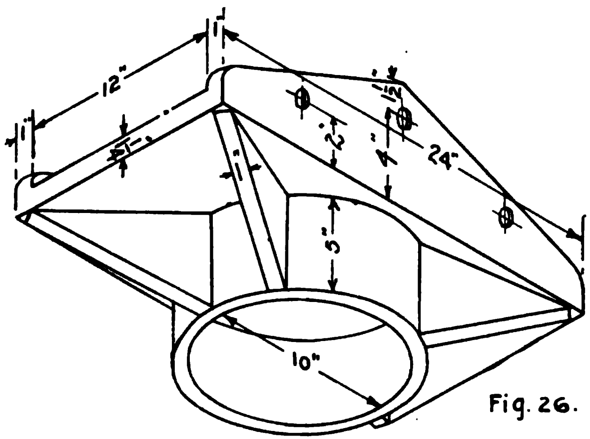


Fig. 26.

Figure 27 is an illustration showing how necessary, sectional views are to the understanding of complex mechanical constructions, while Fig. 28 makes clear how incomplete is the information presented in a mere exterior view of such a mechanism.

The teacher may add similar problems to the above selections at his discretion.

Cylinder for Steam Pump.

Sectional View.

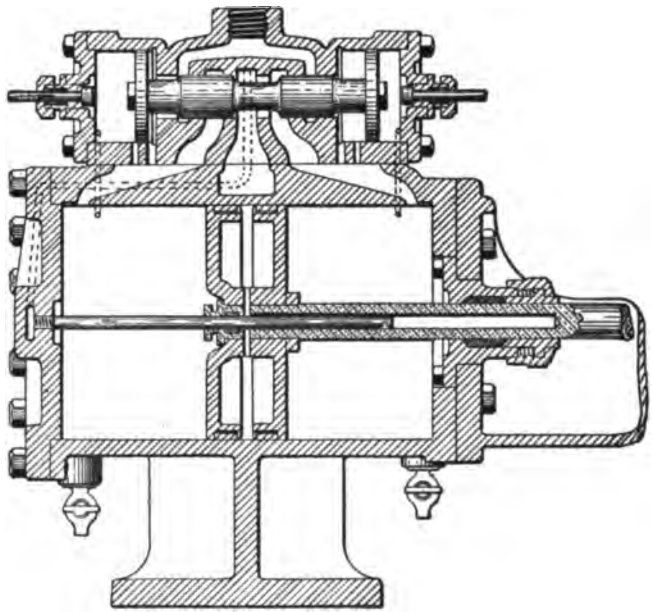


Fig. 27.

Exterior View.

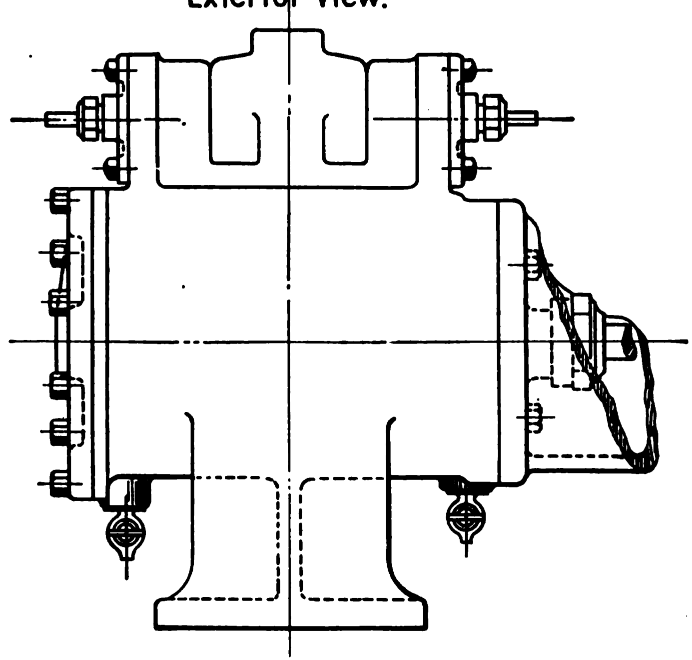


Fig. 28.

Plate 8.—Sections of Solids with Developments.

Problem 1.—Given an oblique pyramid; base horizontal, an irregular pentagon, with one "re-entrant" angle, included within a circle of 1¼" radius, altitude 3". For the meaning of "re-entrant," see the illustrations of polygons, Fig. 3, first year. A plane perpendicular to **V** and inclined at 45 degrees **R** to **H** cuts the axis of the pyramid 1⅝" above the base.

Draw the plan, the front and the side elevations, an auxiliary showing the true size of the section, and develop the frustum. For the development, the true lengths of all lateral edges must be found. Do this by the method explained in the text for Prob. 2, Pl. 6, setting the altitude wholly without the front elevation, to avoid confusion of lines.

The problem is identical in every particular of principle with Prob. 1, Pl. 5. The greater number of sides merely makes its solution longer.

Location.—Place the vertex, in the plan, 2½″ R. and 2″ D.; in the front elevation, 3¾″ D.; in the side elevation, 6⅝″ R.; in the development, 7⅝″ D. and 6¼″ R.

Problem 2.—Given, in an oblique position, an irregular quadrilateral prism with oblique ends. Draw, from an auxiliary view, the front, the top, and the side views, and lay out a development.

The greatest diagonal of a right section of the prism is 1⅝″. Axis of prism, 3¼″ long, parallel with **V**, and inclined to **H** at 37½ degrees **L**. Bases of prism, perpendicular to **V**; lower base inclined 15 degrees R. to H.; upper base, 75 degrees R. to H. Center of axis, **C**, in front view, 4⅞″ D. and 10⅜″ R. Center of circle for right section (auxiliary view) is on the axis of the front view produced, and 2⅜″ D. Axis in side view, 15″ R.

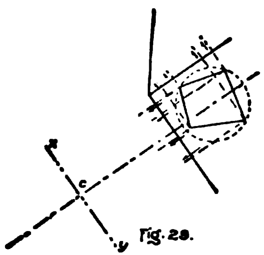


Fig. 29.

Suggestions.—Draw, for the front view, an axis of indefinite length. Thereon locate the center of the circle for the auxiliary view, and draw this view, any irregular quadrilateral resembling that in Fig. 29, one diagonal of which is a diameter of the circle.

From this auxiliary view, the front and the top views can be obtained by a process just the reverse of that used to obtain an auxiliary view, when the top and the front views are given; see Fig. 7, etc. Letter all points in all views after completing them.

Development.—The right section of any prism always shows the true widths of its lateral faces; hence, the auxiliary view, which, for the development, may be considered as a right section made by a plane, as **x-y**, Fig. 29, gives this necessary information.

In the development, the trace of plane **x-y** will be a straight line perpendicular to the lateral edges of the prism. Draw this trace horizontal, and 8⅞″ D. On it, set off the widths of the faces and draw the lateral edges through these points.

The front view gives the true lengths of the lateral edges. Using the trace of the plane, **x-y**, as a base line, take the distances from it to the upper and lower ends of the edges, and transfer these measures to the corresponding edges in the development, setting them respectively above or below the trace of the section plane. By connecting the extremities thus determined, the development, showing the bevels of the bases, can be completed.

Next, the true sizes of the bases must be found. This can be done in several ways, by evolution, by an auxiliary view, or by construction.

The first two methods, which have already been explained, are shown in Fig. 30. Note that the results are identical. Fig. 31 illustrates the third method—i. e., by construction.

In the top view, Fig. 31, assume any line parallel with V (as **x-c**) as a base line, and upon it project the vertex of the angles of the polygon in points **a′**, **b′**, and

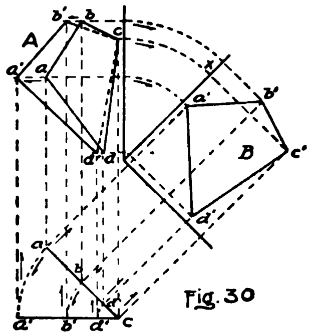


Fig. 30

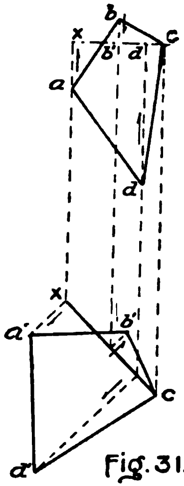


Fig. 31.

d′. The front view of this base line, coinciding with the front view of the plane, is the true extreme width of the polygon, and also shows the true measures of the widths between the vertices of the angles; Rule 12.

In the top view, the distances **a-x, b′-b,** and **d′-d** are taken perpendicularly to V; therefore are parallel with H; hence appear in truth; Rule 12. These give the true extreme depth of the polygon and the true relative depths of the vertices of its angles in reference to the base line.

Now, it is evident that, if the true depths, shown in the top view, be combined with the true widths, shown in the front view, on the base line **x-c**, by the co-ordinate method (Prob. 5-6, Pl. 2, First Year), the true size of the polygon will be established. Notice that the resulting figure is the same as that found by the first two methods, Fig. 30. Also, by comparison, it will be seen that the off-sets in Fig. 31 (**a-x, b′b, d′-d**) correspond exactly with the like off-sets from line **x-c′** in the auxiliary view, Fig. 30-B. In fact, the result in Fig. 31 may be considered as an auxiliary view obtained by construction, the oblique planes and the evolutions being omitted.

In this way, find the true size of each base of the prism. The sides of these should check the corresponding lines in the development. Attach them, being careful to do this properly—i. e., so that like edges would meet if the development were folded up.

In inking, show all construction lines, also ink the true sizes of the bases in dashed red lines.

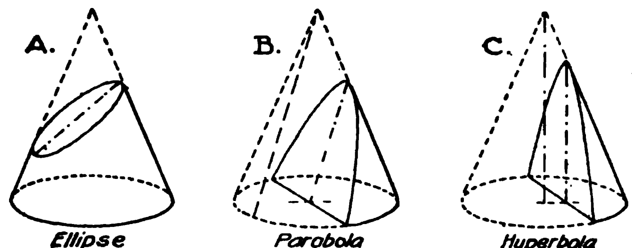


Fig. 32.

Plate 9—Conic Sections with Developments.

If a section be made through a right circular cone by a plane passed parallel with its base and cutting all its elements (see "Definitions"), the resulting figure will be a circle.

If this plane is oblique to the axis of the cone and cuts all its elements, the figure will be an ellipse, Fig. 32A.

If the plane is passed parallel with one element (cutting the base), the figure will be a parabola, Fig. 32B.

If the plane is passed parallel with the axis of the cone (but not coinciding with it), and cuts the base, the figure will be an hyperbola, Fig. 32C.

Problems.—Given three, right circular cones, each with a base of 1¼″ radius and an altitude of 3½″. In the top view, the axis of the first is 2⅜″ R.; of the second, 8″ R.; and of the third, 14⅜″ R. The axes of all are 2″ D. In the front view, the bases of all are 7¼″ D.

(1) **Ellipse.**—Pass a plane perpendicular to V and at 45 degrees L. to the base of the cone—i. e., 45 degrees R. to H. Find the sectional surface of the top view, and draw an auxiliary of it showing its true size.

(2) **Parabola.**—Pass a plane parallel with the right element (perpendicular to V) and cutting the base ½″ to the right of the axis. Find the sectional surface in the top view, and draw an auxiliary view showing the true size.

(3) **Hyperbola.**—In the top view pass a plane parallel with V, and with the axis of the cone, and cutting the base ⅝″ in front of its axis. Find the sectional surface in the front view.

Suggestions.—In the top view, divide the base of each cone into sixteen equal parts. Draw elements from these points, in each view. Number these elements. In each problem, the points in which these elements are cut by the sectional plane establish the trace of that plane in the conical surface. The elements of a cone correspond to the lateral edges of a pyramid, the section line passing through points in them being a free-hand curve, however. Section points on elements, the projections of which are perpendicular to HA, will be found by projecting them from the front or the top view to the side view of these elements, as the case demands; but an actual side view is unnecessary in the problems, inasmuch as the right or left element of the front view is the equivalent of a side view.

Developments.—Locate the vertices of the cones on a base line ½″ above and parallel with the lower border line; first vertex, 2½″ R.; second, 7½″ R.; third, 12½″ R., one element of each development coinciding with the base line.

Locate the traces of the cutting planes, getting the true positions of the necessary points by measuring upon the right or left elements of the front views, their distances from the vertices of the cones. Transfer these to the elements of the same number in the developments. Attach the sections, but omit the bases. Ink all removed portions in dotted lines. Tint.

Plate 10.—Practical Problems.

For Plate 7 the pupil was provided with dimensioned sketches from which to make working drawings of the objects shown.

For this plate he must make his own sketches, inserting the dimensions, and from these he must make a complete working drawing of the model, including a sectional view, all drawn to a suitable scale. The sketches may be ee-hand working sketches, or they may be oblique views of the objects, resembling Figs. 18, 19, 21, 25, 26.

A globe or a gate valve, a machinist's or a steam fitter's vise, a stereopticon, an hydraulic press, a grocer's scales, a stock, a Stillson wrench, a model of a slide valve and a cylinder, or some other object from the physical laboratory or the engine room may be assigned, at the discretion of the teacher.

The drawings should be laid out and executed with care; all views fully dimensioned; the sections "hatched"; shadow lines and line shading used in inking; and the plate furnished with a neat title and border line.

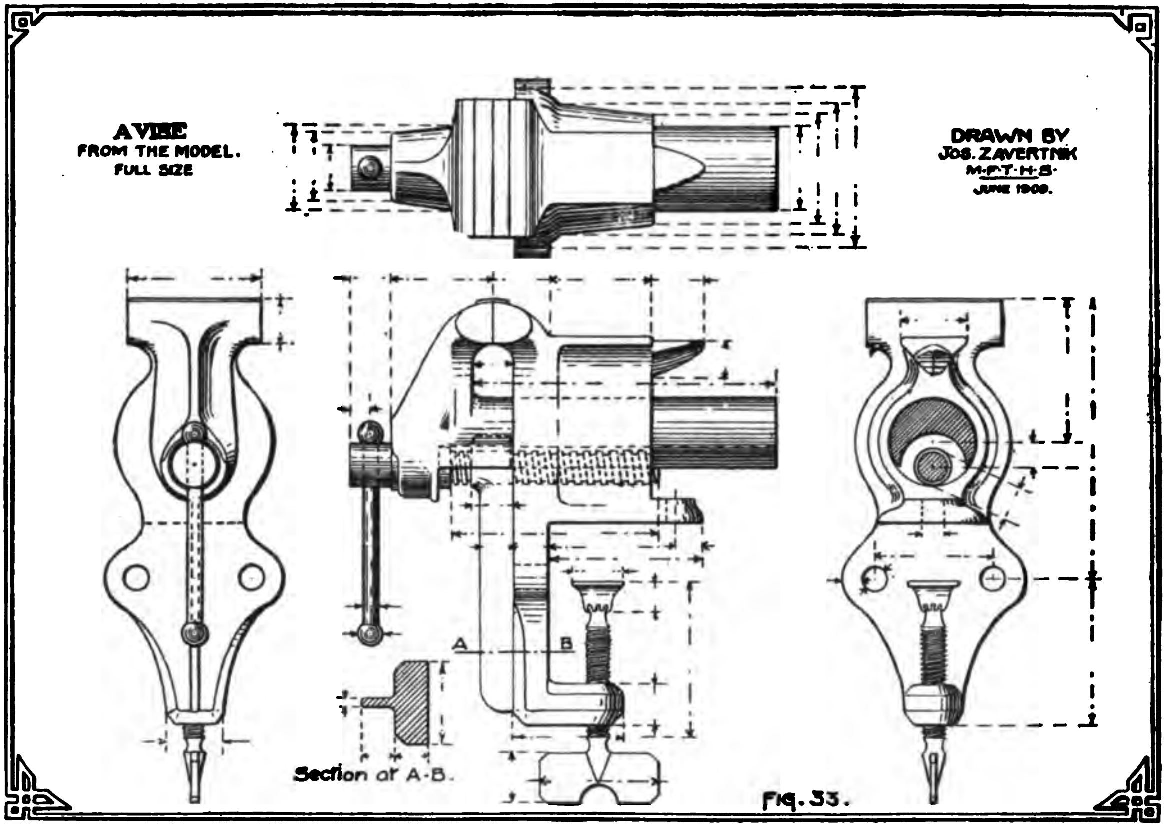


FIG. 33.

Figure 33 illustrates how attractive such drawings may be made even when a very commonplace object is used. The pupil should not attempt such complete line shading as here shown, but should try his hand, if at all, only upon some of the simpler parts. Also, Fig. 33 shows how fully, and the manner in which the drawing should be dimensioned.

Or, instead of inking the plate when done in pencil, the pupil may make a tracing of it in ink, on tracing cloth, as is the more general drafting room practice. Trace on the dull side of the cloth, first rubbing with chalk dust.

It is from such tracings that "blue prints" are made and the original drawings duplicated.

THIRD YEAR.
PENETRATIONS.
Introductory Text.

In preparing the text for the subject at hand, Penetrations, it was assumed that the pupil thus far has followed the instructions carefully, and has done his work with understanding. Therefore, further explanations of general terms, of elementary processes and principles, will be omitted from the succeeding pages. Neither will the particulars of solution be given in such detail as heretofore, nor should the pupil expect them; as the work advances, the pupil must depend more upon his own power to apply principles previously used, thus reasoning out the solutions, and less upon text, in which "it has been thought all out" for him, and which often "shows him how," as well. Needed explanations will not be wanting, however. These are to be followed, step by step, precisely as given.

The workmanship of this year should be decidedly superior to that of the preceding, and in it the pupil should take pride and be ambitious to excel.

Penetrations.—Penetrations, or the cutting or intersecting of one or more forms by another, occur in practice in a large part of the objects of which working drawings are made, as in the penetration of roofs by chimneys, by towers, by dormer windows, etc., in the intersection of pipes and flues in tee, cross, and elbow joints, and in machinery in the joining of hubs and spokes of wheels, etc.

The subject is a direct continuation of that immediately preceding—namely, Sections—inasmuch as the problems in penetrations require for their solution the determining of the various sectional lines resulting from the partial cutting of the surfaces of one object by those of another.

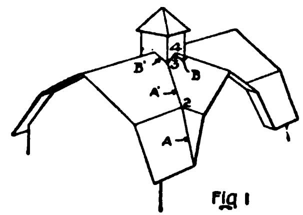


Fig 1

In the accompanying illustration, Fig. 1, two intersecting curb roofs crowned by a cupola, note the lines **A**, **A'**, in which the roof surfaces intersect, and the lines **B**, **B'**, in which the cupola penetrates the roof. To determine such lines of penetration it is necessary to locate points common to the two intersecting surfaces of the objects, in this case, points **1**, **2**, **3**, **4**, etc. Then these must be joined in proper progression, as **1** with **2**, giving line **A**; **2** with **3**, giving line **A'**, etc. Thus a continuous line is established, its parts following one another in the order of the successive intersecting surfaces, as **A**, then **A'**, then **B** or **B'**, etc. This sequence is invariable, providing no surfaces or edges of the objects are common—i. e., coincide to form one.

Two planes intersect always in a straight line; hence in the penetration of plane surface solids, it is necessary to find only the points in which the edges of each penetrate the surfaces and edges of the other, as shown in Fig. 1.

But in the penetration of one curved surface solid with another, or with a polyhedron, it is usually necessary not only to establish the points in which the

edges penetrate, but also to locate many other points, intermediate, common to the intersecting surfaces of the objects, because the line of penetration may be made up largely or wholly of curves.

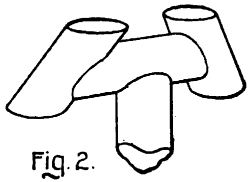


Fig. 2.

Note the curved lines of penetration in the sketch of a chimney top made of cylindrical pipes, Fig. 2, to establish which numerous points common to their intersecting surfaces had to be found.

Statement of the Problem.—Draw the views of the object so as to show their axes in their true relation; that is, assume the forms in a position in which their center lines are parallel with one and the same plane of projection. Then the points necessary to determine their lines of penetration may be found by the use of one or both of two general methods.

Solution—First Method A.—The points may be found from the views on H., V., and S. V., by noting where the edges of each object penetrate the surfaces of the other, and in the incomplete views, by locating and connecting them in correct succession.

Thus, in Fig. 3, the points of penetration of the edges of the horizontal prism appear in the top view, **1, 2, 3**, etc., while those, **A. B**, of one edge of the vertical prism are evident in the side view. Now, by carrying such points from these two views to the front view as shown, and there connecting them, the pupil may easily establish the lines of penetration. This method is particularly applicable to right penetrations of prisms. At this point the pupil should begin Plate 1, referring to the following Methods of Solution as the work advances.

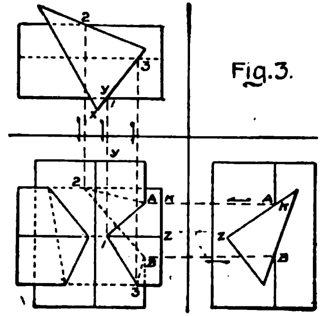


Fig. 3.

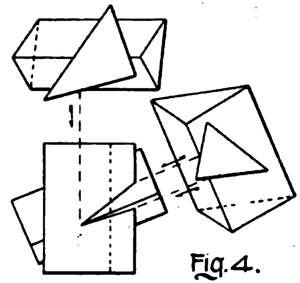


Fig. 4.

B.—The points may be found from the top and front views with the help of an auxiliary view taken upon a plane perpendicular to the axis of the object which presents an oblique view in the statement of the problem.

Although in Fig. 4, the problem is but partially solved, there is sufficient to show that, once the auxiliary view is obtained, the process of working out the lines of penetration in such an arrangement is identical with that just explained, Method A. It is seldom necessary to draw the complete auxiliary view. In this case, for example, the end view of the oblique prism showing where one edge of the other prism penetrates it, is really the only important thing; all else is unnecessary. Hence, in such views useless parts should be omitted, when once the method of obtaining them and their practical use are understood. This method is particularly applicable to oblique penetrations of prisms.

Second Method.—The points may be found by passing cutting or sectional planes through the inter-

secting solids. To insure accuracy, this should be done in such a way as to make the sections in each object simple, easily drawn figures. The points of intersection in the outlines of the figures thus obtained are points in the lines of penetration of the two forms.

The sections may be made in various ways.

A.—By extending the bounding planes of one of the objects, thereby making sections through the other.

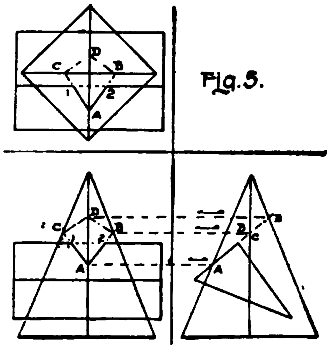


Fig. 5.

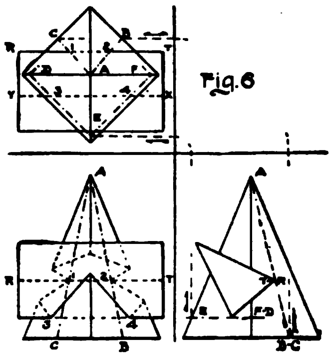


Fig. 6

In Fig. 5 we have merely the statement of a problem, showing how such sections are made. Thus, in the side view, the front upper surface of the prism, if produced, will cut the pyramid in the sectional figure **A-B-D-C.** As apparent in the front view, the sides of this figure are actually cut in the points 1 and 2 by the upper edge of the prism, for this edge lies in the sectional plane; hence these are the points of its penetration with the lateral faces of the pyramid. And the lines **A-1** and **A-2**, parts of the figure **A-B-D-C,** are also parts of the line of penetration of the two forms. By continuing this process, the pupil may establish the remaining portions of this line. The complete sectional figures are never needed in this and the following methods of solution; hence the pupil should draw only that which is of use, in this illustration lines **A-B** and **A-C.**

This manner of passing planes is applicable especially to combinations of prisms and of the prism and pyramid. In oblique arrangements, an auxiliary view would be substituted for that on S. V., and the work done in exactly the same way as above explained.

B.—By passing cutting planes coinciding with the axes, edges and elements of one or of both the intersecting forms.

Thus, in Fig. 6, by passing a plane along the edge of **T-R** of the prism, through the vertex of the pyramid and cutting the base of the latter, the sectional figure **A-B-C** is formed, shown in the front and top views. The points 1 and 2, in which the sides of this figure are cut by the edge of the prism along which the plane was passed, are the points of penetration of this edge with the lateral faces of the pyramid.

This method, with some slight variations in its application, is adapted to combinations of almost every kind. By it, the points of penetration of the remaining edge of the prism, Fig. 6, may be found, but for the sake of illustration, we will find these in a different way.

C.—By passing a horizontal plane coinciding with the edge **X-Y**, this being parallel with the base of the pyramids, the section made will be a figure (**D-E-F**) similar to that of the base as shown in the top view. The points 3 and 4, in which the edge **X-Y** of the prism cuts the sides of this figure, are its points of penetration. This method is best suited to right penetrations of prisms, of cylinders and of either of these forms with the pyramid and the cone.

D.—In Fig. 7 is shown a use of vertical cutting planes. In such arrangements, where this method is used, an abbreviated side or auxiliary view supplies all that is needed to establish the figures formed by the sections made. In this problem, in each object these figures are parallelograms. Their intersections fix points in the line of penetration. It will be even

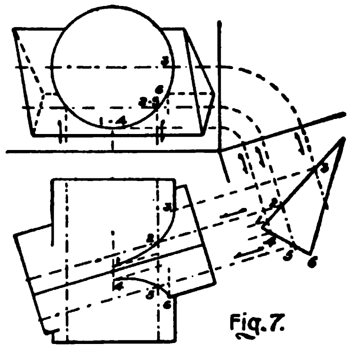


Fig. 7.

more simple to consider the traces of these vertical planes in the lateral surface of the cylinder merely as elements of the cylindrical surfaces which are cut by the faces of the prism, and then to find the points in the line of penetration by the First Method, **A** or **B**, connecting them by curves, of course. This method is adapted to arrangements of forms the elements of the lateral surfaces of which are parallel with their axes, such as right and oblique combinations of prisms, of the prism and cylinder, and of cylinders.

The pupil should so thoroughly familiarize himself with the practical application of these various methods as to have them at his very finger tips, as it were. And he will find that in mastering the subject of penetrations he will have mastered at the same time the essential principles of the whole subject of orthographic projection.

Developments.—The developments of the objects having been laid out entire, the problem is then—How are the lines of penetration to be established therein? To which the answer is—By correctly transferring the various points in these lines from the projections of the objects to their developments, and there properly connecting them.

Such points as fall in the edges of the objects will give us no trouble to locate, providing we do not forget always to establish their positions on the true lengths of the edges on which they occur, if these are not already evident, just as was the practice in laying out developments in Sections.

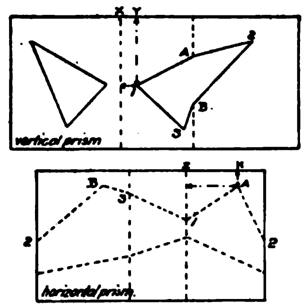


Fig. 8.

Prisms and Cylinders.—Points between edges in the developments of prisms are easily transferred by using the co-ordinate method. Thus in Fig. 3, the developments of which are shown in Fig. 8, point 1 lies in the right face of the vertical prism, the distance **X-Y** (top view) of the width of this face from the front edge and the distance **Y-1** (front view) of

the length taken from the top. In the horizontal prism the point **A** in the upper face lies in the distance **Z-K** (side view) of its width from the front edge, and the distance **K-A** (front view) of its length taken from the nearer end. In like manner any intermediate points may be similarly referenced and transferred to the developments.

In developing cylinders, utilize uniformly spaced elements, as lines of reference, and then proceed as with prisms.

Pyramids and Cones.—Points on conical surfaces, and those lying in the lateral surfaces of pyramids are transferred in several ways.

1. Corresponds to Second Method A. By the intersections of the traces of the sectional planes used in first determining the points.

2. Corresponds to Second Method B. By drawing the traces of the oblique sectional planes, and locating the points on these in exactly the same way in which points are transferred from lateral edges—i. e., by getting their true lengths and establishing the positions of the points thereon.

3. Corresponds to Second Method D. By drawing the traces of the sectional planes when these are parallel with the base of the pyramid or cone, and transferring thereto the distances directly from the view (the top view usually) wherein are shown the true positions of the points in reference to the lateral edges or to the elements.

For General Application.—By the intersection of the traces of the sectional planes and elements of the surfaces drawn where convenient through various points in the line of penetration.

The corresponding parts in the lines of penetration in the developments of objects of the same problem should be equal. This is the proof of the accuracy of the work, and the pupil should check his developments in these particulars before inking either them or the projections from which they were taken. This is easily done by numbering consecutively the points in the original line of penetration, and then giving the same numbers to like points in the developments; see Fig. 8.

It is usual to ink the line of penetration solid in the development of one object to show the opening caused by the passage of the other through it, and in the second the line is then inked dotted; see Fig. 8.

Definitions—Right and Oblique Penetrations.—If the axis of two penetrating forms are perpendicular to each other, the penetration is a right penetration. If otherwise, it is an oblique penetration.

Regular and Irregular Penetrations.—If the axes of the penetrating forms intersect, or lie in the same plane, the penetration is regular. If otherwise, it is an irregular penetration. Thus, penetrations may be right regular and oblique regular, or right irregular and oblique irregular.

The pupil will find that in the statements and specifications for various of the problems, some particulars of size and arrangement are lacking. In such instances, he is to supply these according to his own judgment as to what will be satisfactory; the practical draftsman must know how to proportion and to place his drawings.

Lettering.—As exercises in lettering, the pupil will design and print each month from September to April a title for some imaginary drawing, using letters of appropriate styles and sizes. See Figs. 5 and 43, First Year, also the accompanying text. The wording for these titles will be supplied by the teacher.

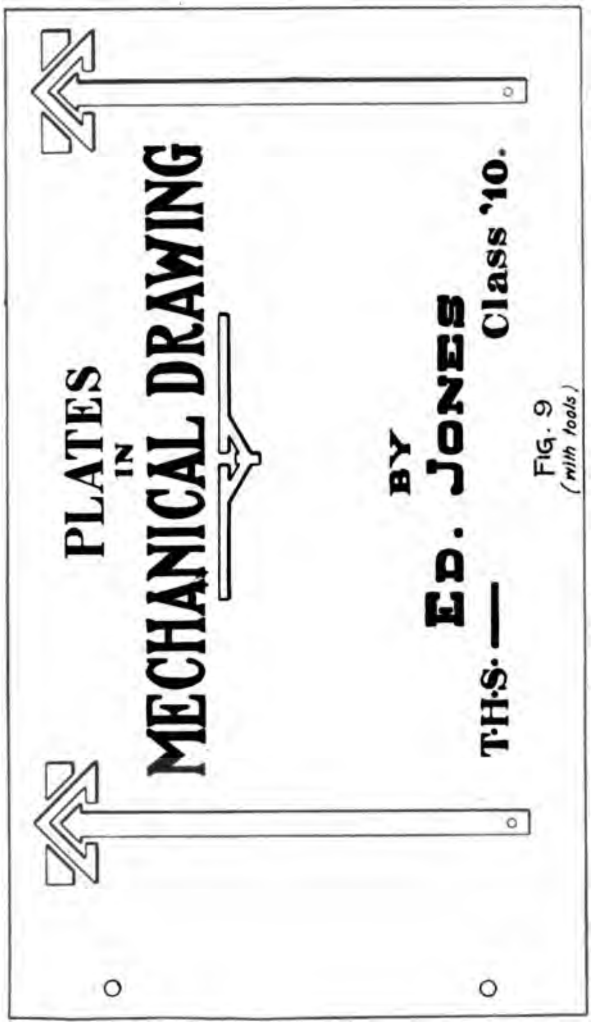


FIG. 9
(with tools)

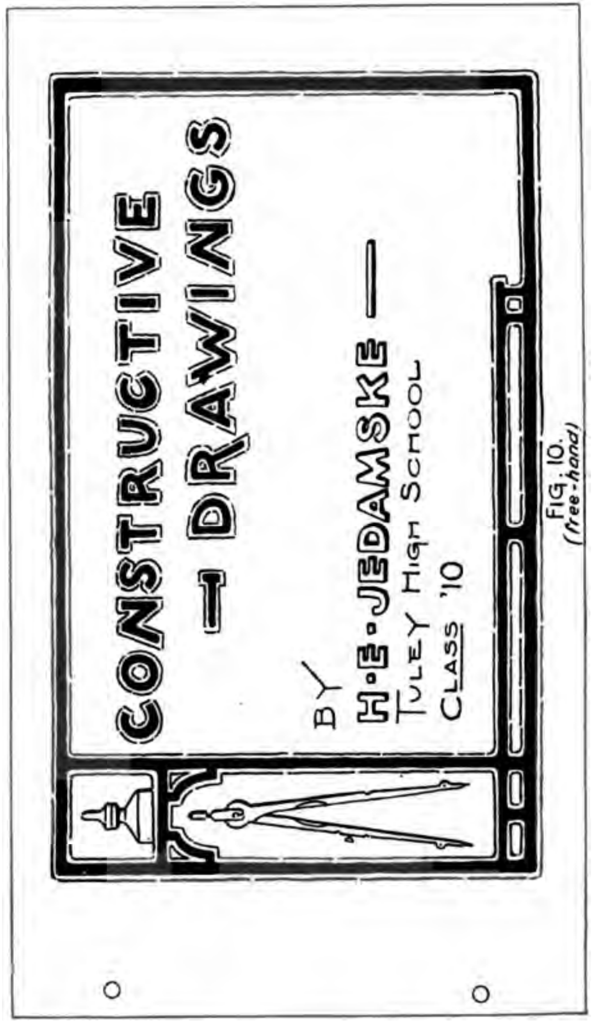


FIG. 10.
(free-hand)

For May and June, the problem will be the design of a title page for the portfolio of plates, to be made upon a sheet of the same size as the plates and to be bound with them when it is completed.

These designs should be studied out and executed carefully. They should have a distinctly artistic quality, for titles are not only useful and necessary upon drawings, but they also are or should be decorative. The evidence of nicety of workmanship and of taste in the design of these particulars as well as in the making of the drawings themselves, distinguishes the real draftsman from the mere bungler, the slovenly one.

In the design of the title page (a book panel), the groupings of lines and of shapes should parallel the outlines of the inclosing figure, so that thereby its rectangular character may be emphasized. And the shapes used must be related to its outlines in order that the design may be one distinctly adapted to the shape of the panel. The lines employed may be simple or elaborated border lines or band-like inventions corresponding thereto. Or our panel may be subdivided into agreeably proportioned minor panels within some of which figures may be developed. These band borders and panel figures should be geometric or conventional rather than organic in character, they may include appropriate emblems of mechanics, etc., and among the shapes to be used the words of the title also much be included.

The pupil should "spot" his scheme of design—i. e., study out in sketches the best placing of the various items of the composition before attempting to develop any one portion.

The lettering may be of any appropriate style, standard or designed by the student. It should not be over-ornate. The design may be illuminated in various ways, by tinting, by shadow lining, etc., and by this means made attractive. See Figs. 9 and 10.

Text of the Problems.

Plate 1.

Problem 1.—A right square vertical prism, altitude 2½″, diagonal of base 2¼″, is penetrated by a right square horizontal prism, length 2¾″, diagonal of base 1¼″. One diagonal of the base of each prism is parallel with V. H. A. is 3½″ D. Axis of vertical prism in top view 1¾″ R. and 1½″ above H. A. Axis of horizontal prism is ¼″ either in front of or behind the axis of the other. In the front view, projections of axes are centered 1¾″ below H. A. H. A. and V. A. intersect 3½″ R.

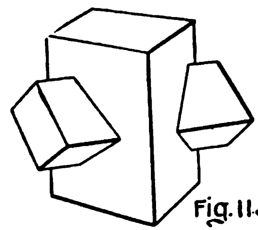


Fig. 11.

Top view.

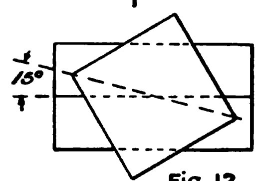


Fig. 12.

Solution.—Use side elevation to find points of penetration not directly obtainable from other views; First Method A. Letter both objects completely and number all points of penetration. See Fig. 11.

Problem 2.—A right square vertical prism, altitude 2½″, diagonal of base 2¼″, is penetrated by a right square horizontal prism, length 2¾″, diagonals of base 1½″. One diagonal of base of latter is parallel with V., and the axis of the prism is parallel both with V. and with H. Penetration is right and regular.

Axes intersect in the top view 8″ R. and 1½″ above H. A. One diagonal of base of vertical prism is inclined at 15 degrees R. or L. to V., Fig. 12. In the front view axes intersect 1¾″ D.

Solution.—Use side view as in previous problem. H. A. and V. A. intersect 9¾″ R. Proceed as before, then lay out developments of both problems in space below and to right of work just done. Locate penetration lines therein, checking them. Read paragraphs on Developments. Ink and tint. In inking the views we quite commonly imagine that the smaller penetrates the larger form, and then omit altogether those portions of the edges of the latter which thus would be removed, as in these two problems we would dot the edges of the horizontal prisms through the vertical, but would omit those of the latter where cut away by the former. Developments are inked correspondingly. Developments are given uniformly a light, flat tint, excepting where openings occur.

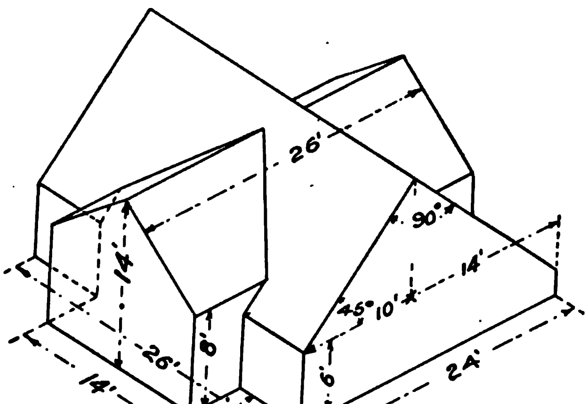


Fig. 13.

Plate 2.

Given two irregular, pentagonal prisms (resembling a barn roof) arranged as shown in the isometric sketch, Fig. 13. Longest axis of larger prism is perpendicular to V.; that of the other is parallel with both V. and H. H. A. is 5½″ D. Scale, ⅛″ to 12″.

(1) Draw top, front and side views. Projections of axes intersect in top view 2¾″ R., and 2¾″ above H. A. In front view base common to prisms is 2¼″ below H. A. Find lines of penetration by use of First Method A.

(2) Turn top view of (1) so that axis of larger prism is at 60 degrees R. to V., and work out corresponding front view, showing all penetration lines.

(3) Lay out developments, left to right across the plate, in space below views, axes vertical. Omit ends. Show penetration lines, reference and check them.

Plate 3.

Problem 1.—A right, irregular, penetration of a prism and a pyramid. A right, square, horizontal prism 3″ long, edge of base 1¼″, is penetrated by a right, regular, vertical pentagonal pyramid of 3¼″ altitude and 1½″ edge of base. Rear edge of base of pyramid is parallel with V. and with H. Axis of prism is perpendicular to S. V. and centered 1¼″ above the base of the pyramid and ¼″ in front of the axis of the latter. Lowest face of the prism is at 22½ degrees R. to base of pyramid, as apparent in the side view. Base of pyramid 7¼″ D. Three views to occupy left one-half of plate; developments to be below. Omit bases from developments.

Solution.—Draw the top, front, and side views of the pyramid, then the side view of the prism, etc. Produce sides of prism on S. V. as cutting planes in

determining penetration lines on top and front views, and in development of pyramid, Second Method A, using corresponding method in developing. Second Method B or C could be used equally well.

Problem 2.—Practical example. Given a spire in the form of a square pyramid, having dormer windows on two opposite angles; see Fig. 14.

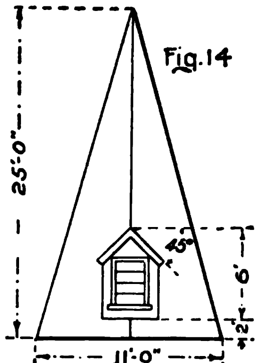


Fig. 14

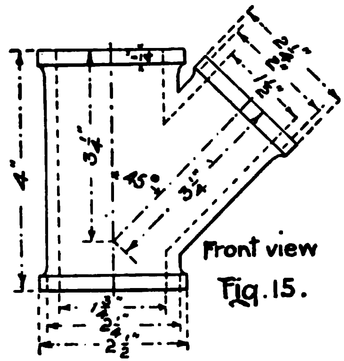
Side view.

Common axis of dormers is parallel with V. and with H. Drawing to occupy upper right half of plate. Base $7\frac{1}{4}''$ D. Scale, $\frac{1}{4}''$ to $12''$. Upper part of spire broken off in front view to allow space for its top view. Find penetration lines by the method used in the previous problem. Shadow line and dimension; do not tint practical problems. No developments.

Plate 4.

Problem 1.—Oblique penetration of a right, circular cylinder and an irregular prism. A right, vertical, circular cylinder $3\frac{1}{2}''$ altitude and $2\frac{1}{2}''$ diameter is penetrated by a right, irregular, triangular or quadrilateral prism $4''$ long, its base inscribed in a circle of $2\frac{1}{4}''$ diameter. Axis of prism is parallel with V, and inclined $22\frac{1}{2}$ degrees L. to H. Draw top and front views of cylinder first, then auxiliary showing right section of prism, as in Prob. 2, Plate 8, Second Year, and thereafter draw the other views of the prism. Finally draw developments of both objects, omitting bases. Axis of cylinder $3''$ R.; base $7''$ D.

Solution.—Second Method D, Fig. 7. Use vertical cutting planes parallel with V., passing one through each edge of the prism and two or more between each two edges. Do not draw the whole cutting, but only the abbreviated section or element lines. Use the traces of these planes in establishing the penetration lines in the developments.



Front view

Fig. 15.

Problem 2.—Practical Example. Given a Y branch, Fig. 15. Draw three views, and work out the line of penetration for both the inner and outer cylinders. Axis of main pipe $10''$ R., base $7\frac{1}{2}''$ D. Do not draw flanges until penetration lines have been found.

Solution.—Same as for Problem 1. Divide the circumference of the branch into 16 equal parts, and pass a vertical cutting plane through each division of pipe, drawing, however, only the element lines. No developments.

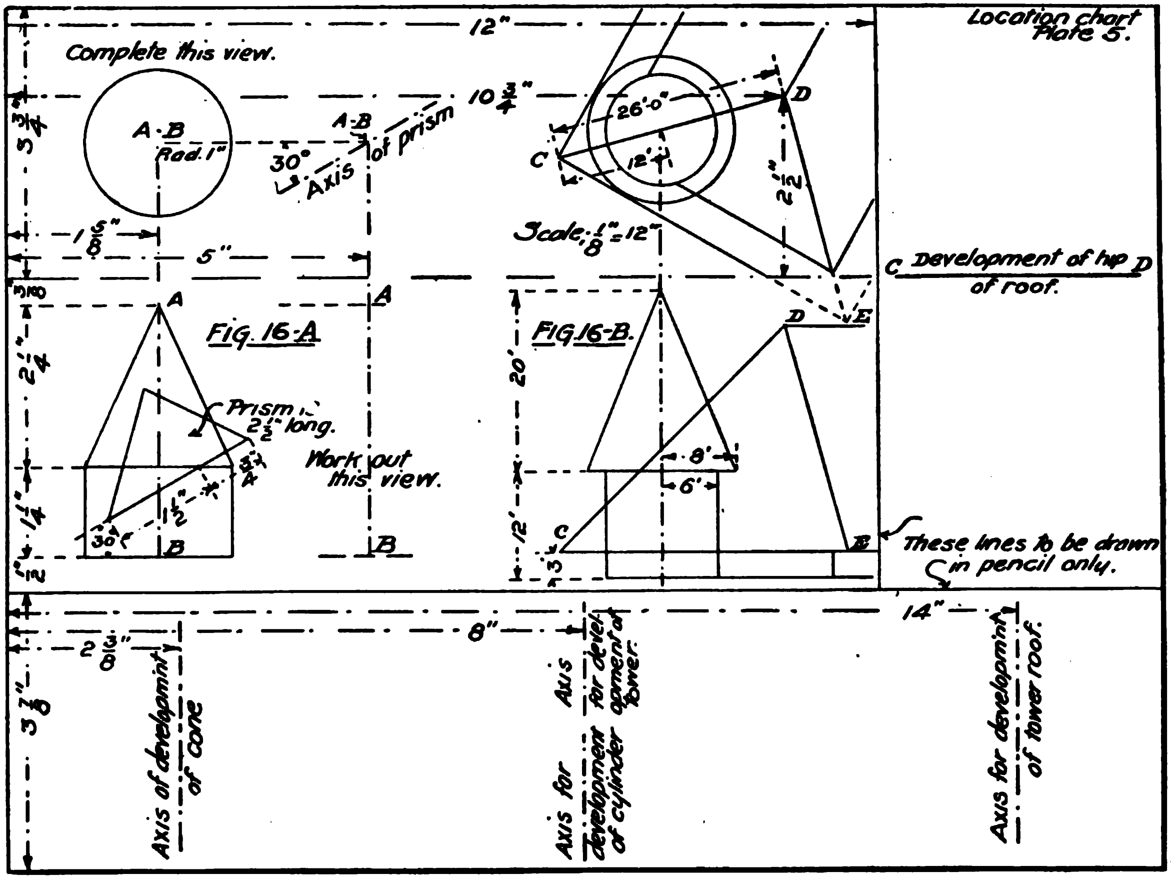


Plate 5.

Problem 1.—Right irregular penetration of a prism with a cone and a cylinder. A cone and a cylinder are arranged as shown in the accompanying location plate, Fig. 16A, and are penetrated by an irregular triangular prism the axis of which is perpendicular to V.

(1) **Solution.**—Second Method C. By the use of horizontal sectional planes, work out the penetration lines in the top view. These will be evident in the cone only.

(2) Transpose the top view just drawn to the position indicated, axis of prism inclined at 30 degrees R. to V., lowest edge to back; get corresponding front view showing lines of penetration thus far found, and complete these lines on the cylinder by the same method of solution used in (1).

(3) Develop the cone and cylinder, but after Prob. 2 has been solved.

Problem 2.—Practical example. This represents the penetration of a hip roof by a cylindrical tower having a conical roof as shown in location plate, Fig. 16B. In the top view, hip **C-D** is at 15 degrees R. to V., and at 90 degrees to hip **D-E**. Also in the front view the hip **C-D** is at an angle of 45 degrees with the eave **C-E**, but in laying out the development later, the pupil must not assume any of these to be the true angles. This problem is solved in precisely the same way as that used in Prob. 1. Place the developments where shown, using method of laying out corresponding with the method of solution used.

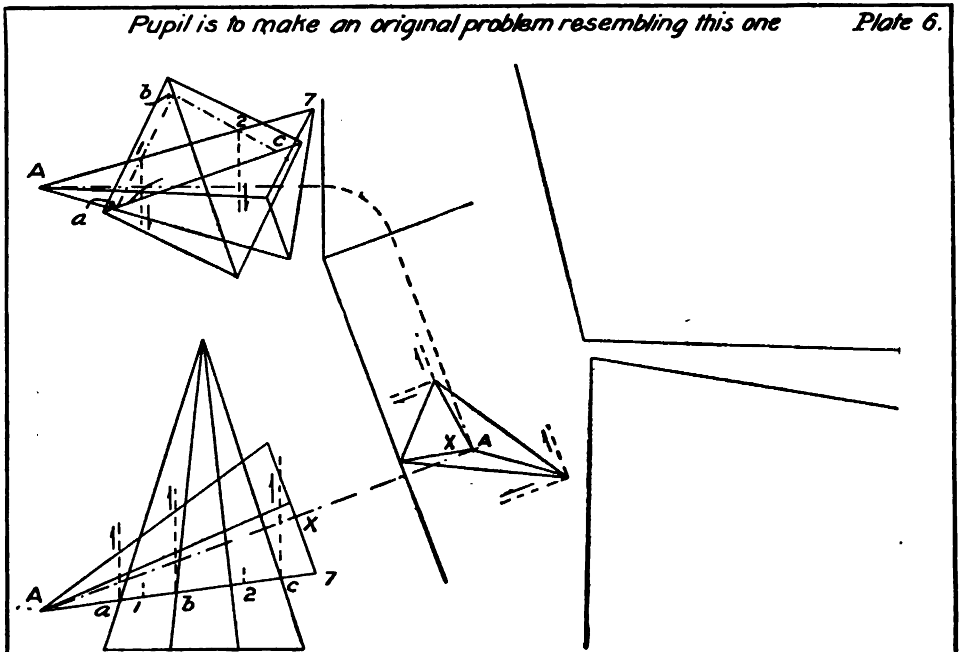


FIG. 17

Plate 6.

A right, square pyramid is penetrated by an irregular triangle pyramid; arrangement about as shown in the accompanying illustration plate, Fig. 17. Draw top, front, partial auxiliary, and developments, working out the lines of penetration complete. Pupil is to determine the exact proportion, arrangement, and placing of work.

Layout.—Draw the top view of the square pyramid, then its front view. Across the front view draw the axis **A-X,** indicating proposed position of the triangular pyramid. Extend this axis, and on a plane perpendicular thereto, draw the auxiliary view of the triangular pyramid only. Then construct its corresponding front and top views.

Solution.—Second Method B. Pass sectional planes perpendicular to H., coinciding with the lateral edges of the vertical pyramid, and like planes perpendicular to V. coinciding with the lateral edges of the oblique pyramid. For example, a plane thus passed through edge **A-7** would cut the vertical pyramid in part in the figure **a-b-c**, top view. The intersections of edge **A-7** with the sides **a-b** and **b-c** of this figure (the traces of the sectional plane) in points **1** and **2** are the points of its penetration with the lateral faces of the upright pyramid. Continuing this process, the pupil may find the points of penetration of all other edges in both forms.

In laying out the developments, it is practicable to use traces of horizontal planes as explained in Developments of Pyramids and Cones, Third Method, or we might apply the Fourth Method equally well.

Supplementary Problems—Fig. 18.

These problems, at the discretion of the teacher, may be substituted for any involving like principles, in the first six plates, but they are especially intended for another purpose.

If upon the pupil's completion of the first six plates, the teacher knows that the pupil cannot apply intelligently the sectional plane methods of solution thus far explained, it is recommended that the pupil be given such of the supplementary problems or similar ones in place of Plates 7, 8, and 9, as will make these processes clear to him.

Problems A, B, and C correspond to those of Plates 3 and 5. Problems D, E, and F correspond to those of Plate 4, and Problem G, to that of Plate 8.

Description.

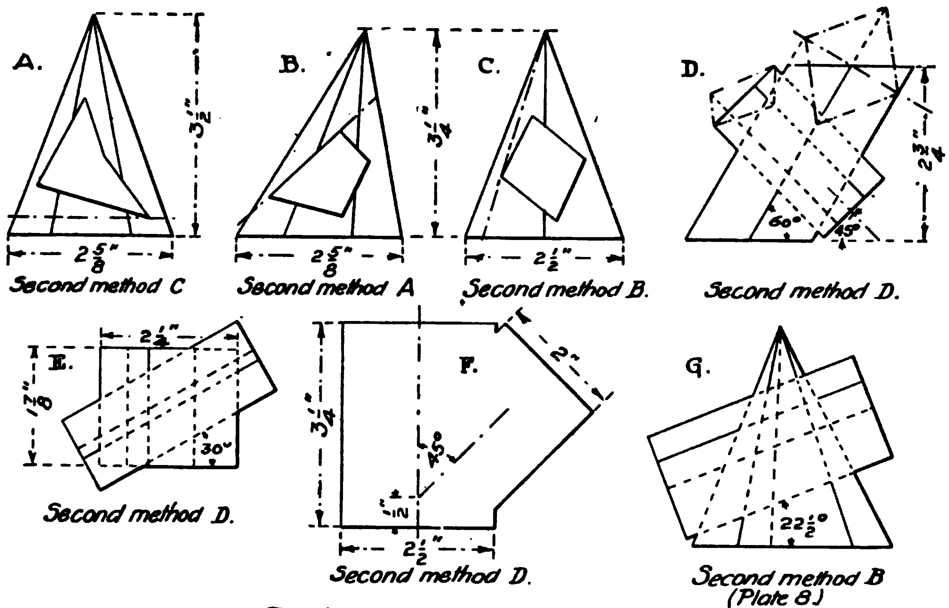
Problem A.—Given the side view of a vertical, regular hexagonal pyramid penetrated by a horizontal, irregular quadrilateral prism, any length, having one re-entrant angle. Draw top and front views, establish penetration lines therein and develop.

Solution.—Second Method C, by horizontal sectional planes.

Problem B.—Given the side view of an oblique, irregular quadrilateral pyramid penetrated by a horizontal, irregular quadrilateral prism, any length. Draw the top and front views, get the lines of penetration, and lay out the developments.

Solution.—Second Method A, by oblique sectional planes coinciding with the faces of the penetrating object. Exactly the same as Prob. 1, Plate 3.

Problem C.—Given the side view of a vertical, square pyramid penetrated regularly by a horizontal,



Supplementary Problems. Fig. 18.

rhombic prism of any convenient size. Obtain the top and front views, the lines of penetration and the developments.

Solution.—Second Method B, by oblique sectional planes coinciding with the edges of the penetrating object.

Problem D.—Given the front view of an oblique, rhombic prism penetrated irregularly and obliquely by an irregular triangular or quadrilateral prism, axes parallel with V. Draw the top and front views, find the lines of penetration, and lay out the developments.

Solution.—Second Method D, by use of vertical sectional planes coinciding with the lateral edges of each object.

Problem E.—Given the front view of a vertical, irregular pentagonal prism penetrated irregularly and obliquely by an irregular triangular or quadrilateral prism, axes parallel with V. Draw the top and side views, get the lines of penetration, and lay out the developments.

Solution.—Second Method D, by use of vertical sectional planes and abbreviated auxiliary view. See Fig 7.

Problem F.—Given the front view of a sheet iron, circular cylindrical pipe penetrated irregularly and obliquely by another circular cylindrical pipe, the axis of the second being ¼″ in front of the axis of the first, the axes of both being parallel with V. Get all the views, the lines of penetration and the developments.

Solution.—Second Method D. This is identical with Prob. 2, Pl. 4, but there are no inner lines of penetration to be found.

Problem G.—Given the front view of an irregular, pentagonal pyramid penetrated obliquely and irregularly by an irregular quadrilateral prism, both objects of any size suitable to the plate. Draw the top and an auxiliary view, find the lines of penetration, and lay out the developments.

Solution.—Second Method B, by the use of oblique sectional planes coinciding with the edges of the penetrating object, in combination with a full auxiliary view of the two forms. See Plate 8.

Plate 7.

Given a sphere and an irregular pyramid of any number of sides, arranged about as shown in Fig. 19. Find the lines of penetration in the horizontal and vertical projections and lay out developments of pyramid and of one hemisphere showing lines of penetration in the former only.

Solution.—Second Method B. Pass cutting planes perpendicular to H. through all the lateral edges of the pyramid, and thus find points in which each of such edges penetrates the sphere. For example: In the top view pass a plane coinciding with the edge **x-3**. This plane, as all planes do, cuts the sphere in a circle. Rotate this section and the edge complete, about the axis of the pyramid until they are parallel with V. Then their vertical projections will be shown to intersect in two points, **a** and **b**, which are the points of penetration of this edge with the sphere. Proceed in the same manner to find like points in all other

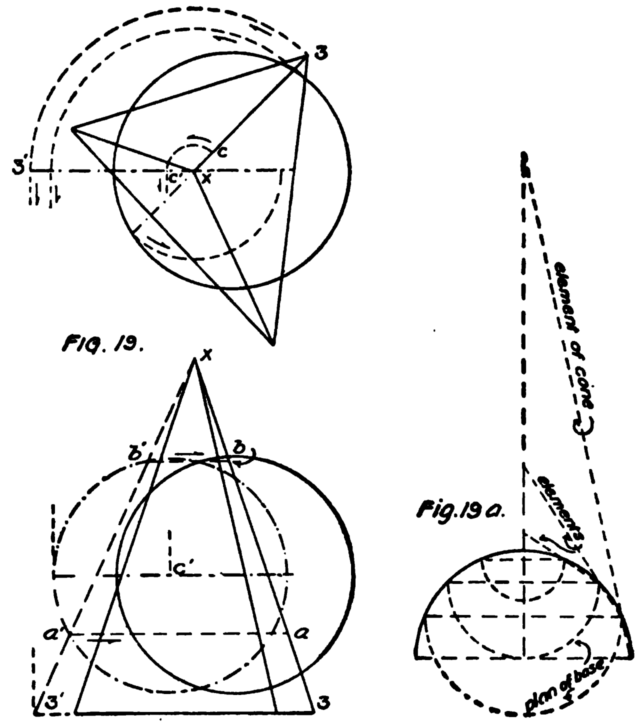


FIG. 19. *Fig. 19 a.*

edges. To find the necessary intermediate points, draw several straight lines from the vertex to the base of each lateral face. These we might consider as elements of those surfaces. Find their points of penetration by the same method used to determine such

points of the lateral edges. Should one or more of the lateral edges fall without the sphere, it may be advisable to pass several horizontal cutting-planes as described in Second Method C. In fact, this problem might be solved by their use, but not so advantageously as by the method already explained.

Development.—After the development of the pyramid has been drawn and the points of penetration of its edges have been transferred thereto, inasmuch as all sectional lines are arcs of circles, it remains only to find the centers for the circles which pass through these points. This may be done by producing to their intersection the perpendicular bisectors of any two chords formed by joining the penetration points on the same or adjacent edges. To draw the development of the hemisphere, divide its semi-circular profile into zones of uniform width, four or more, and lay out each zone as though it were the frustum of a right circular cone, drawing the sections tangent upon a common meridian; see Fig. 19a. There is another method of developing the sphere, but it is even more of an approximation than this, and of much less practical value.

Plate 8.

A right, circular cone is penetrated obliquely and irregularly by a right, circular cylinder, as shown in Fig. 20. Establish the penetration lines in the top and front views, and lay out the developments showing these lines therein.

Solution.—After drawing the statement of the problem, construct an auxiliary view of the combination upon a plane perpendicular to the axis of the cylinder, this view of the latter being then a circle. The points in which this circle cuts the elements of the cone are points in the line of penetration. By carrying these from the auxiliary to like elements in the other views, this line may be located in them. This is an application of Second Method B. Thus, on

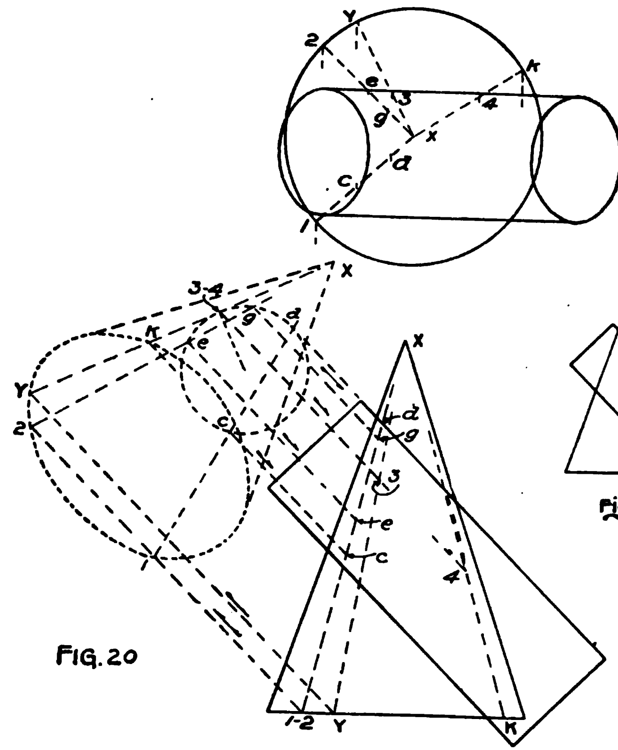


FIG. 20

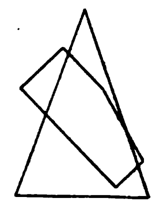


FIG. 20a.

elements **X-1** and **X-2**, **e** and **g**, and **c** and **d** are such points. A plane passed through the vertex of the cone tangent to the cylinder cutting the former in elements **x-y** and **x-k**, will determine the location of the points of nearest approach, **3** and **4**, in the oppos-

ing parts of the curve of penetration on the front, which we might call, for convenience, the "extreme" or "transition" points. This problem can be made more interesting by cutting the cylinder as shown in Fig. 20a, or it can be simplified by passing the cylinder through above the base of the cone. Also, a prism may be substituted for the cylinder.

Development.—To lay out the development it is best to draw twelve or more uniformly spaced elements on the cylindrical and conical surfaces, and to transfer their points of intersection with the curve of penetration to like elements in the developments as described in the paragraphs on Developments. For the cone see the second method under the heading, Developments of Pyramids and Cones.

Plate 9.

Two, right circular cones, I and II, Fig. 21, of any size, penetrate irregularly in an arrangement similar to that shown. Draw the horizontal and vertical projections complete, and lay out the development of one of the cones, showing penetration lines.

Solution.—To find points in the lines of penetration, pass sectional planes through the vertices of the cones, cutting the cones along their elements. This is an application of the Second Method B. The figures thus obtained will be triangles. The vertex of each triangle thus found will be common with that of the cone of which it is a section. The points of intersection of the sides of two triangles made by one cutting, are points in the line of penetration. All these cutting planes will intersect in a straight line connecting the vertices. The point **B** is the trace of this line in the auxiliary horizontal plane **J-H**, which we have assumed for convenience as coinciding with the base of Cone I. In order not to spread our work needlessly, suppose we pass an oblique auxiliary plane perpendicular to **V.**, coinciding with the right ele-

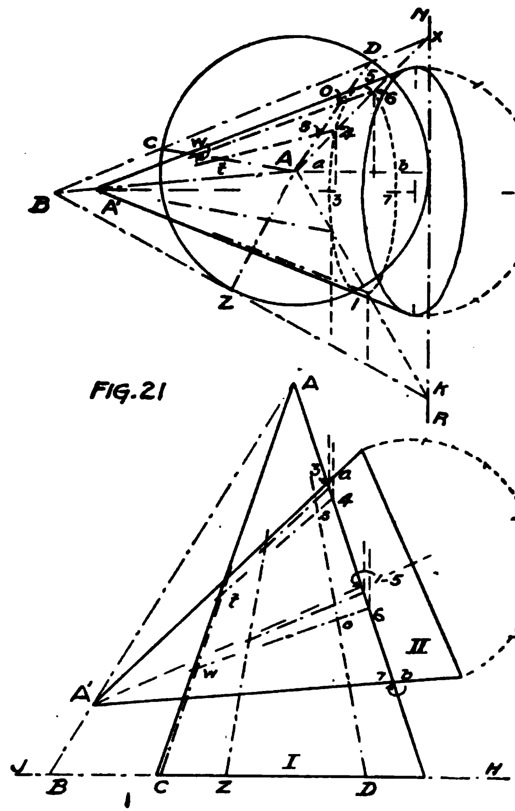


FIG. 21

ment of Cone I, cutting Cone II in figure 1-3-5-7, which we may assume as a temporary base to that cone. The trace of this plane with the auxiliary **H.**

is the line **R-N**. The traces of all oblique planes passing through the vertices **A** and **A′** of the cones will be, in this oblique auxiliary plane, straight lines from **A** to points in the line **R-N**. And the traces of such oblique planes with the auxiliary **H**. will be lines drawn from these points on **R-N** to point **B** already established. Keeping in mind that the traces just mentioned lie respectively in the same planes as the bases of the cones, then the pupil will see that the cutting of these bases by the traces of the same sectional plane will determine the triangles the intersection of whose sides give points in the line of penetration.

For Example.—In the oblique auxiliary plane, draw any line as **A-X**, top view, cutting the base of Cone II in points **4** and **6**. Now **A-X** is really the trace of an oblique sectional plane with this auxiliary. Its trace with the auxiliary **H**. is **X-B**, which cuts the base of Cone I in points **C** and **D**. The two triangles made by this one section are **A-C-D** in Cone I, and **A′-4-5** in Cone II. The intersections of their sides, elements of the conical surfaces, give us points in the line of penetration, as **w** and **t**, and **o** and **s**. The trace of a plane in the auxiliary **H**. draw tangent to the base of Cone I, as **B-K**, will determine the element (**Z-A**) in which must lie "extreme" points in the line of penetration. Corresponding points at the back may be found by drawing a trace in the oblique auxiliary, tangent to figure **1-3-5-7**.

In like manner other points may be found, at least 16 or 20 being needed to establish accurately the curves of the line of penetration. Incidentally it may be noted that the points **a** and **b**, wherein the figure **1-3-5-7** is cut by the right element of Cone I, are points in the line of penetration.

This method of solution is applicable to combinations of pyramids and cones, and of oblique as well as right cones. Also it may be used in arrangements of pyramids, the sectional planes being then passed through their lateral edges; but the method explained in Plate 6 is preferable.

Development.—This is laid out in the way employed in the previous problem, Plate 8.

Plate 10

ISOMETRIC AND CABINET PROJECTIONS.

We have already noted that in orthographic projection two or more views of an object must be drawn to represent it fully. Also that, in general, in that method of projection, oblique views, being more pictorial, give a clearer idea of the form of the object represented than do simple ones. But, for actual construction, oblique views are not practicable because, properly, they should not be dimensioned, for they cannot be made "scaleable" throughout.

A method whercby we can show correctly in one view the relative positions of the surfaces of an object and also its essential dimensions, would be a great convenience. Fortunately there are two such methods which, within a limited field, may be utilized as substitutes for orthographic projection.

Isometric Projection.—If we place an object, a cube for example, in such an oblique position that its three principal axes are equally inclined from any one of the planes of projection (the vertical is usually taken), we shall find that all will be foreshortened in equal degree; therefore all such axes and, of course, all edges parallel therewith, could be scaled. Now although the ratio of foreshortened to true length is about 9 to 11, in practice all these lines are laid off to scale according to their actual lengths.

Figures so drawn are represented in what is called Isometric Projection—isometric meaning equal measure.

Figue 22 shows the usual manner of making a drawing by this method, viz., two sets of axes extended, one to the right, one to the left, each at 30 degrees to a horizontal, and the third set drawn vertical, all sets drawn to scale. But no other lines or sets of lines and no angles are shown in their true lengths and sizes.

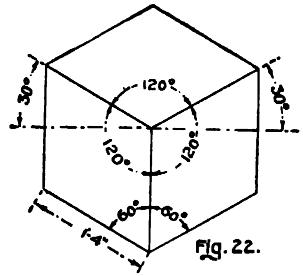


Fig. 22.

Definition.—Then, Isometric Projection is that method of representation wherein the vertical projections of the three axes of an object which are perpendicular to each other (and edges parallel therewith), meet in angles either of 60 or of 120 degrees.

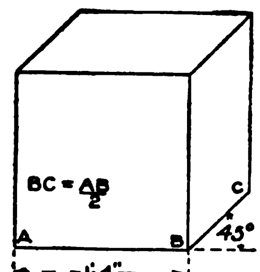


Fig. 23.

Cabinet Projection.—This is wholly an invention of the draftsman. It may be defined as that method of representation wherein the objects drawn are shown with those of their surfaces which are parallel with the vertical plane of projection in their true size and

shape, while those of their edges and all dimensions perpendicular to the vertical plane are shown inclined arbitrarily at either 30 degrees, 45 degrees, or 60 degrees, to a horizontal, and usually made but one-half of their actual length. See Fig. 23. Fig. 24 shows an isometric view of the little stool from Plate 6, First Year, while Fig. 25 is a cabinet projection of the same object, both drawn to the same scale.

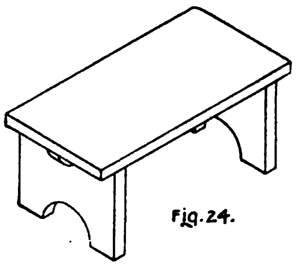


Fig. 24.

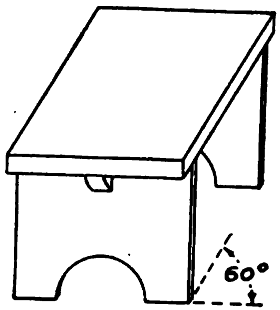


Fig. 25

Notice in the illustrations that something of the effect of perspective is secured, while at the same time the views show the three axes in such a way that the articles properly may be dimensioned.

These methods are used extensively, especially the first, in machine drawing to represent engine parts and details of assembling, and methods of construction and joinery in buildings; also in catalogs and circulars advertising machinery, mechanical appliances, fittings, furniture, etc. Furthermore, they are used quite generally in the making of drawings for the Patent Office.

Small drawings, usually of rectangular forms, are most satisfactory; very large ones are seldom made, as they are quite awkward to produce and present a disagreeably distorted appearance.

Very recently a hexagonally ruled paper has been put upon the market for convenience in making isometric sketches.

Before working out the problems on the plate with the instruments, the pupil must make, on other paper, and submit for criticism, a freehand sketch of each object shown in Fig. 26, or such similar objects as the teacher may direct.

This will not be difficult to do if he will keep in mind that the representation is merely an oblique projection of the object.

Some facility in such free-hand sketching is a valuable asset to the general draftsman. Very frequently he is called upon to make such pictorial sketches, from the orthographic projections, or the projections from the sketches, so that he has need to be alike familiar with both methods of representation. Figs. 18 to 26, Second Year, include examples of isometric sketches drawn from ordinary projections of the objects.

The free-hand sketches having been approved, the plate may be begun. In this make the drawings according to the dimensions and arrangement shown in the location chart, Fig. 26. Draw the problems in the order in which they are lettered. R. P. means "reference point", which is the point of beginning in drawing the outlines of each object. It is located by distances from the upper and the left border lines. Unless otherwise stated, make all drawings full size. The title of the plate is to be, Problems in Isometric and Cabinet Projections, and is to be placed where directed.

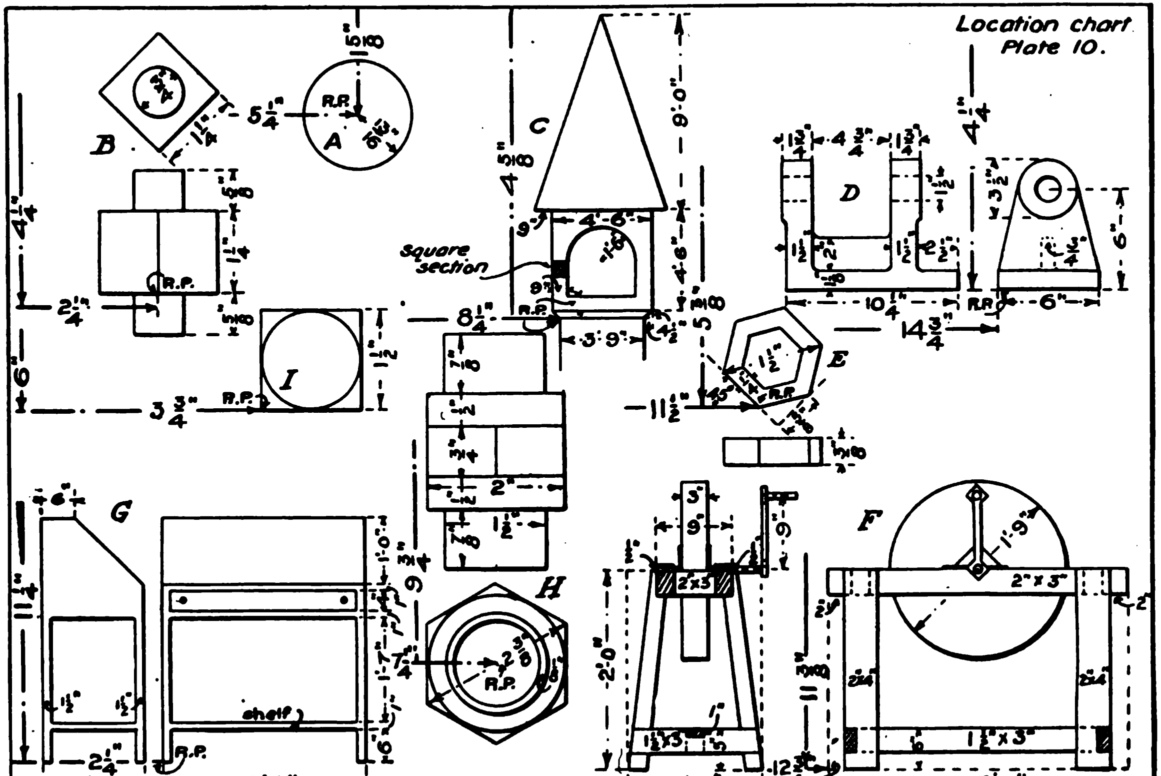


FIG. 26

The Problems.

Isometric Projection.

Problem 1.—(Fig. A) Make an isometric projection of a horizontal circle, using the four centered approximate ellipse method shown in Fig. 27. Also see Fig. 37, Supplementary Prob. 12, First Year. Fig. 28 is the method of drawing the isometric projection of the circle free-hand.

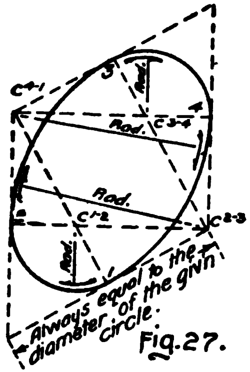


Fig. 27.

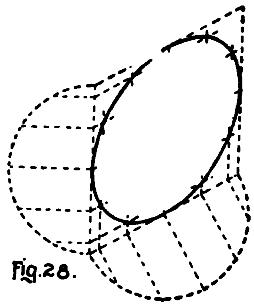


Fig. 28.

Problem 2.—(Fig. B) Make an isometric projection of a cube which is penetrated by a cylinder, from the top and front views of the combination.

Problem 3.—(Fig. C) Make an isometric projection of a square belfry tower from its front view. Represent it as if it were above the horizon. Scale, 1/3″ to 12″. Get this from the scale, 1″ to 12″.

Problem 4.—(Fig. D) Make an isometric view of this shaft stand from its front and side elevations. Draw it with its length to the left and its width to the right from R. P. Scale, 3″ to 12″.

Problem 5.—(Fig. E) Make an isometric projection of a hollow, regular hexagonal plinth, one diagonal of which is at 45 degrees L. to V., given its top and front views. Inclose it in a parallelogram as shown. Recollect that the length of one side equals one-half that of a diagonal.

Problem 6.—(Fig. F) Make an isometric projection of a grindstone and stand from its front and side views. Draw it with its length to the right and its width to the left from **R. P.**, which point is the front, lower, left corner of the inclosing rectangular prism shown by dotted lines. Scale, 1½″ to 12″.

Cabinet Projection.

Problem 7.—(Fig. G) Make a cabinet projection, suitable for a catalog illustration, of a writing desk or similar article of furniture, showing the full depth to the left from **R. P.** at 30 degrees according to the front and side elevations shown. Scale, 1″ to 12″.

Problem 8.—(Fig. H) Make a cabinet projection of a union pipe joint from its front and top views, drawn retreating at 30 degrees to the right from **R. P.**, and one-half of its actual length.

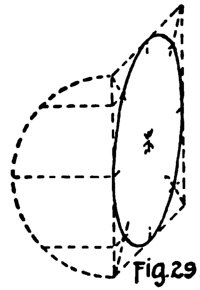


Fig. 29.

Problem 9.—(Fig. I) Make a cabinet projection of a cube having on each face a circle tangent to its sides. Top and right face to show at 45 degrees, and to be one-half their actual depth. See Fig. 29.

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